



**Quality Assurance and Quality
Control
using Opsis analysers
for Air Quality Monitoring**

Version 1.4

Copyright

© Opsis AB. All rights reserved. This manual and the software described in it are copyrighted with all rights reserved. No part of this publication may be reproduced, transmitted, transcribed, stored in a retrieval system or translated into any language in any form by any means without the written permission of Opsis AB. Opsis AB authorises the purchaser to make one copy of the software for back-up purposes. Information in this document is subject to change without notice.

Trademarks

OPSIS is a trademark owned by Opsis AB, Sweden. Other brands and product names are trademarks or registered trademarks of their respective companies. Companies, names, and data used in examples herein are fictitious unless otherwise noted.

Limited warranty on software

The warranty conditions of this software are described in the purchase agreement between the buyer and the seller. However, a condition for any warranty is that the software is installed, operated and maintained in accordance with the specifications and instructions issued by Opsis AB including this manual. This warranty is limited to replacement of defective diskette or documentation supplied by Opsis AB and in no event shall Opsis AB or its suppliers be liable for any loss of profit or any other commercial damage, including but not limited to direct or indirect, special, incidental, contingent or consequential damages resulting from any defects in the software or its documentation including damages from loss of data, downtime, loss of goodwill, damage to or replacement of equipment or property.



Contact information

Address	Opsis AB Box 244 SE-244 02 Furulund, Sweden
Telephone	+46 46 72 25 00
Fax	+46 46 72 25 01
Web-site	http://www.opsis.se
E-mail	info@opsis.se

Contents

1	Introduction	1
1.1	Overview	2
1.2	Interval summary	3
1.3	Report sheets	4
1.4	Safety precautions	14
2	Installation criteria	15
2.1	Analyser hardware	15
2.2	Measurement site	16
2.3	Path lengths	17
2.4	Measurement time	17
2.5	Temperature and pressure correction	18
2.6	Special fence-line application precautions	18
2.7	Using the site data report sheet	19
3	Hardware function	21
3.1	Light levels	21
3.1.1	Light optimiser LO 110/LO 150	22
3.1.2	Selecting gases and studying light levels	22
3.1.3	Allowed variations	22
3.1.4	Daily variations	23
3.1.5	Slow changes	24
3.2	System check	24
3.3	Disk space and analyser clock	26
3.4	Site inspection and data backup	27
3.5	Wavelength precision	28
3.5.1	Hardware requirements	28
3.5.2	Performance	28
3.5.3	Alternative procedure: View residuals	29
3.6	Lamp change	30
3.7	Analyser overhaul	31
3.8	Using the hardware function report sheet	31
4	Measurement performance	33
4.1	Reference check	33
4.1.1	Hardware requirements	33
4.1.2	Initial preparations	34
4.1.3	Performance	35
4.2	Multipoint span/offset calibration	36
4.2.1	Hardware requirements	38
4.2.2	Performance	41
4.2.3	Calculation example	43
4.3	Function check	46
4.3.1	Hardware requirements	46
4.3.2	Selecting gas concentrations	47

4.3.3	Performance	49
4.3.4	Calculation example	51
4.4	Light attenuation test	52
4.4.1	Hardware requirements	52
4.4.2	Performance	54
4.5	Oxygen backgrounds	54
4.5.1	Hardware requirements	55
4.5.2	Selecting a proper recording occasion	55
4.5.3	Performance	56
4.6	Precision test	58
4.7	Accuracy audit test	58
5	Data validation	59
5.1	Collecting measurement data	59
5.2	Analyser function and performance	60
5.3	Light levels and deviations	61
5.3.1	Lowest acceptable light level	61
5.3.2	Signal to noise ratio	62
5.3.3	Lowest acceptable concentration	64
5.3.4	Using Enviman ComVisioner	64
5.3.5	Example	65
5.4	Aromatic hydrocarbon zero levels and deviations	66
5.4.1	Finding the zero level	66
5.4.2	Aromatic hydrocarbon deviations	69

Every measurement system requires quality assurance and quality control (QA/QC) of measurement data. An Opsis gas analyser is no exception. For an Opsis system, there are several QA/QC procedures applicable for different situations and used to assess different segments and functions of the system.

Recommendations issued by the manufacturer and requirements from the authorities do not necessarily coincide concerning performance and frequency. Whenever conflicts arise, the most stringent requirements and intervals should be implemented.

This manual describes the QA/QC procedures recommended by Opsis AB for analysers of the AR 500 system and of the System 300 types. The descriptions are intended for an average installation, with normal quality requirements. The procedures or intervals may have to be modified in order to meet specifications for specialized system applications and installations. Any additional instruction given by the Opsis representative deviating from what is described in this manual should be followed. Such instructions may put either more or less stringent requirements on the QA/QC procedures. In no case should requirements issued by authorities be neglected.

1.1 Overview

Figure 1.1 shows an example of a sequence of measurement data recorded by an Opsis ambient air monitoring station. The purpose of implementing the QA/QC procedures is to ensure that the measurement data is a reliable representation of the actual air pollutant(s).

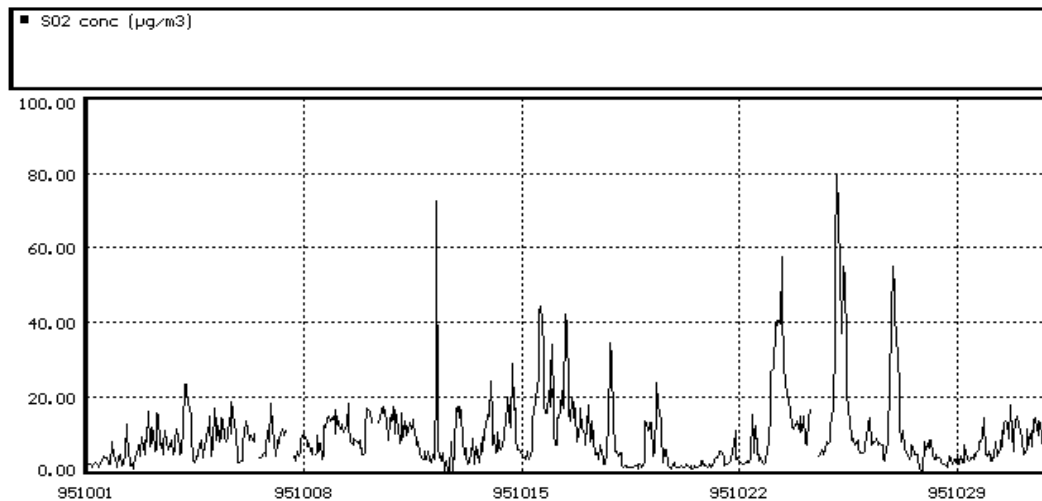


Figure 1.1. SO_2 concentration recorded in an urban area during one month.

As in any other measurement application, the following questions arise:

- Does a zero instrument reading correspond to a zero gas concentration? The baseline (or zero level) of the instrument must be established.
- What is the precision, accuracy and linearity of the instrument? The instrument must be calibrated to respond correctly to any actual gas concentration within a reasonable measurement range.
- Is the reading affected by other parameters than what the reading represents? There should be no interferences, neither from other gases, nor from parameters like operating temperature, mains voltage, and so on.
- What is the stability of the instrument? The instrument must respond in the same way to a given gas concentration throughout the entire period of operation. The baseline or response should not drift in time.

The answer to the above questions can e.g. be found in the instrument specifications. However, to maintain these specifications throughout the operating life of the instrument, a number of quality assurance procedures must be followed. The QA/QC procedures recommended by Opsis AB can be grouped as follows:

- **Installation criteria**
Whether the system is a permanent or mobile installation, a number of siting requirements must be met prior to starting the measurements. These requirements include e.g. measurement site, path lengths, measurement time, and operational conditions for the instrument.
- **Hardware function**
Once the hardware is operational, a number of procedures should be applied to assure the hardware function of the instrument. These include routine checks of the light level in the measurement path, as well as checks of the spectrometer and detectors in the instrument.
- **Measurement performance**
The measurement performance is tested e.g. by means of zero and span measurements, interference tests, and accuracy audit and precision tests. These tests give the answers to the questions above.
- **Data validation**
Data must be validated before being used for any studies or reports. The validation is based both on the results of the function and performance tests, and on status parameters like deviations and light levels being reported as the measurements take place. This is where the information obtained from the result of the other procedures is actually used.

1.2 Interval summary

The table below shows the recommended intervals for various parts of the QA/QC procedures. Explanations and detailed instructions can be found later in this manual.

Table 1.1: QA/QC procedure intervals.

Group	Check/test	Recommended time interval	Section
Installation criteria	Analyser hardware	At installation	2.1
	Measurement site		2.2
	Path lengths		2.3
	Measurement times		2.4
	Temp. and pressure correction		2.5
Hardware function	Light levels ¹⁾	1 week	3.1
	System check ¹⁾	1 week	3.2
	Disk space and analyser clock ¹⁾	1 week	3.3
	Site inspection	local requirements	3.4

Table 1.1: QA/QC procedure intervals.

Group	Check/test	Recommended time interval	Section
	Wavelength precision	1 year ^{2), 3)}	3.5
	Lamp change	6 months	3.6
	Analyser overhaul	1 year	3.7
Measurement performance ³⁾	Reference check	1 year ⁴⁾	4.1
	Multipoint span/offset calibration	1 year ⁴⁾	4.2
	Function check	1 year ⁵⁾	4.3
	Light attenuation	1 year ⁵⁾	4.4
	Oxygen backgrounds	1 year ⁵⁾	4.5
U.S. EPA specific:	Precision test ⁷⁾	2 weeks ^{5), 6)}	4.6
	Accuracy audit test ⁷⁾	1 year / 3 months	4.7
Data validation ⁸⁾	Function and performance	When data is used	5.2
	Light levels and deviations		5.3
	HC zero levels & deviations		5.4

1. Can be performed remotely and/or automatically through a modem connection.
2. Typically performed together with the Reference check.
3. The procedures should be performed at installation, and then with indicated intervals. They may also have to be performed when indicated by the Data validation procedures.
4. Typically performed as a part of the Analyser overhaul.
5. Typically performed immediately after the system is returned from an Analyser overhaul.
6. Only if indicated by the Data validation procedures.
7. These methods are specified by the U.S. EPA, and replaces the Function check procedure when operating under the USEPA 40 CFR 58 regulations. They only need to be carried out when operating under these regulations.
8. May be performed semi-automatically e.g. by the Opsis Enviman software.

1.3 Report sheets

The following pages contain examples of report sheets suitable for recording activities and results of the QA/QC procedures summarized above. Detailed descriptions of the procedures and the usage of the report sheets can be found in later sections in this manual.

These report sheets may have to be extended and/or changed in order to be suitable for specialized installations. In normal installations, however, they should be fully sufficient for record-keeping purposes.

Opsis Analyser for Air Quality Monitoring Site Data								
Analyser S/N					Date			
Site description								
Monitoring	Path 1		Path 2		Path 3		Path 4	
Emitter/receiver								
UF 220/225?								
Path length (m)								
method								
Lamp type, A/B								
Fibre type, 60R/60S								
Fibre length (m)								
Light spot check, OK								
Path light (lux)								
Temp. correction const/logg								
Pressure. correction const/logg								
	Multiplexer, 004/012/024		Fibre type, 60R/60S		Fibre length (m)		Light spot, OK	
Measurement time	Path 1		Path 2		Path 3		Path 4	
	Time	Filter y/n	Time	Filter y/n	Time	Filter y/n	Time	Filter y/n
Gas	:		:		:		:	
Gas	:		:		:		:	
Gas	:		:		:		:	
Gas	:		:		:		:	
Gas	:		:		:		:	
Gas	:		:		:		:	
Gas	:		:		:		:	
Gas	:		:		:		:	
Gas	:		:		:		:	
Gas	:		:		:		:	
Cycle time :								
Operator signature								

Figure 1.2. Site data report sheet.

Opsis Analyser for Air Quality Monitoring Hardware Function							
Analyser S/N		Site location			Date		
Access dial-up/site visit				System check		All ok? y/n	
Time OK? y/n, adjusted (min)				P1=		Final P1=	
Disk space (MB)				P2=		Repeated? y/n P2=	
Backup? y/n				P3=		P3=	
Files removed? y/n, final space (MB)				P4=		Correction P4? y/n P4=	
				P5=		P5=	
Light levels Path/gas	Plot, appx #	Average	Overall change? y/n	Periodic? y/n	Adj. req? y/n	Adj. date	Adj. time
Site inspect.	Em mirror	Re mirror	Win. clean	UV clean	Fibre clean	Light spot	Int. (lux)
Path 1							
Path 2							
Path 3							
Path 4							
Shelter temp			Remarks:				
Fan/filter, OK?							
Wavelength precision, gas	Shift	Adjust y/n	Final shift	Lamp type A/B	Age (months)	Changed? y/n	Next change
				Path1			
				Path 2			
				Path 3			
				Path 4			
Operator signature							

Figure 1.3. Hardware function report sheet.

Opsis Analyser for Air Quality Monitoring Reference Check						
Analyser S/N		Site location		Last calibration		Date
Syst. check	All OK? y/n	Final	λ prec.	Shift	Adjust y/n	Final shift
P1=		P1=	gas			
P2=	Repeated? y/n	P2=	gas			
P3=		P3=	gas			
P4=	Correction P4? y/n	P4=	gas			
P5=		P5=	gas			
Reference light spot OK? y/n			Communication disconnected? y/n			
Reference light intensity (lux)			Initial system name			
			System name changed? y/n			
Reference check and recording						
Gas name						
Unit						
Lamp type, A/B						
UF in use? y/n						
Orig. offset						
Offs. zero OK?						
Orig. meas. time	:	:	:	:	:	:
Meas. time	:	:	:	:	:	:
Light level (%)						
Pre conc, dev 1	,	,	,	,	,	,
Pre conc, dev 2	,	,	,	,	,	,
Pre conc, dev 3	,	,	,	,	,	,
Average conc, dev	,	,	,	,	,	,
Post conc, dev 1	,	,	,	,	,	,
Post conc, dev 2	,	,	,	,	,	,
Post conc, dev 3	,	,	,	,	,	,
Average conc, dev	,	,	,	,	,	,
New ref. required? y/n						
Old ref. restored? y/n						
Offsets adjusted? y/n			Reasonable measurement results? y/n			
Measurement times restored? y/n			System name restored? y/n			
Measurement path reconnected? y/n			Communication reconnected? y/n			
Operator signature						

Figure 1.4. Reference check report sheet.

Figure 1.5. Multipoint span/offset calibration report sheet.

Opsis Analyser for Air Quality Monitoring Function Test/Prec. Test/Accuracy Audit Test												
Analyser S/N			Site location					Date				
Test gas			Test path					Last test				
Initial analyser data		Times/gas										
Path length (m)		path 1 : : : : : : : : : : : :										
Temperature (°C)		path 2 : : : : : : : : : : : :										
Light int. (lux)		path 3 : : : : : : : : : : : :										
System name		path 4 : : : : : : : : : : : :										
Cell length Lc (m)						Preparation:						
Cell temp Tc						Communication disconnected? y/n						
Cal. gas conc.						System name changed? y/n						
Effective conc.						Measurement times deactivated? y/n						
	test gas		interferences									
Gas name												
Unit												
Meas. time	:		:									
Light level	%		%									
Pre conc, dev 1	,		,									
Pre conc, dev 2	,		,									
Pre conc, dev 3	,		,									
Average conc, dev	,		,									
Test conc, dev 1	,		,									
Test conc, dev 2	,		,									
Test conc, dev 3	,		,									
Average conc, dev	,		,									
Post conc, dev 1	,		,									
Post conc, dev 2	,		,									
Post conc, dev 3	,		,									
Average conc, dev	,		,									
Effective conc.			0.0									
Baseline diff.	%		%									
Corrected conc.												
Error	%		%									
Measurement times restored? y/n						System name restored? y/n						
Communication reconnected? y/n												
Operator signature												

Figure 1.6. Function test/Precision test/Accuracy audit test report sheet.

Opsis Analyser for Air Quality Monitoring Oxygen Background Monitoring											
Analyser S/N		Site location		Path		Date					
System check	All OK? y/n	Final		λ precision	Shift	Adjust? y/n	Final shift				
P1=		P1=		gas							
P2=	Repeated? y/n	P2=		gas							
P3=		P3=		gas							
P4=	Correction P4? y/n	P4=		gas							
P5=		P5=		gas							
Initial analyser data											
Meas. light spot OK?		Times/gas									
Meas. light int. (lux)		path 1	:	:	:	:	:	:	:	:	:
Ref. light spot OK?		path 2	:	:	:	:	:	:	:	:	:
Ref. light int. (lux)		path 3	:	:	:	:	:	:	:	:	:
Disconn. comm. OK?		path 4	:	:	:	:	:	:	:	:	:
Initial system name											
System name changed? y/n											
Reference and background recording											
Gas name											
Unit											
Lamp type, A/B											
Ref. recorded OK?											
Back. ref. time (s)											
CA 004?											
CA 004 time (s)											
Back. recorded OK?											
Orig. offs.											
Offs. zero?											
Conc, dev, light 1											
Conc, dev, light 2											
Conc, dev, light 3											
Final offs.											
System name restored? y/n											
Communications reconnected? y/n											
Operator signature											

Figure 1.8. Oxygen background recording report sheet.

1.4 Safety precautions

The safety precautions described in the various hardware operating manuals must be followed. Since some of the quality assurance procedures requires handling of toxic and/or corrosive gases and other substances, the following precautions are extremely important:

- Always study the gas supplier's safety instructions and regulations carefully before handling any gas.
- Gas cylinders must be prevented from falling by means of chains.
- Transportation of gas cylinders may require special precautions and safety arrangements.
- The main valve of the gas cylinder should always be closed when the gas is not in use. Do not only rely on the valve on the gas regulator.
- The gas cylinders should be stored in ventilated, specially provided, storage areas. Toxic gases should be handled preferably outside the workshop or the laboratory. small quantities can be handled inside the building, if possible under well ventilated conditions.
- All fitting parts must be in good condition. A pressure regulator must be inserted between the gas cylinder and the unit where the gas is used. Do not simply throttle the gas flow by adjusting the main valve of the gas cylinder.
- The gas calibration system outlet must be vented outdoors.
- Make sure that all gas connections, tubes etc. are free from leaks. This can be done e.g. by applying soap water around the potential leakage points, and watch for bubbles.

Other precautions may apply based on company, local or other safety regulations.

Before installing an Opsis analyser, a number of things must be considered. If the analyser is used in a fixed installation, the procedures below only need to be implemented once, whereas a mobile system requires new checks each time the system is moved to a new site.

2.1 Analyser hardware

New analysers are always produced according to the latest standards, using the best available technique. The analyser hardware has gradually been modernized throughout the years, and the measurement performance can in some cases be improved considerably by upgrading an existing system. The following items should be checked:

- **Lamp.** Only 150 W lamps should be used. The power supplies for the emitters should therefore be of the PS 150 or PS 150-2 types.
- **Z-drive.** The analyser should be equipped with a so called Z-drive for positioning the grating. In general, all analysers produced after 1990 will have the Z-drive. Contact your Opsis representative if you are in doubt.
- **BTX-grating.** For meeting the latest performance requirements for AQM applications, the analyser can be fitted with a dedicated high resolution grating for BTX. Most analysers delivered after 1999 will have the BTX grating as standard if the analyser is calibrated for BTX (industrial fence-line applications may be excepted). Contact your Opsis representative for more information.
- **Software version.** The descriptions found in this manual is based on version 7.10 of the analyser software. The analyser software should have this or a later version installed.
- **Light spot.** The light spots visible when holding the fibre ends 10-15 cm from a white piece of paper must be smooth and uniform without any shaded areas or circle-like structures. If not, the fibre may be gently bent close to the receiver (multiplexer) end. This scrambles the modes generated inside the fibre. There must *not* be any sharp bends on the fibre close to the analyser connection.
- **Light intensity.** The light intensity obtained from a measurement path immediately after installation should represent the maximum value obtainable. Make a note of this intensity, and always try to achieve the same intensity when adjusting the measurement paths. The reported light intensity may vary from light meter to light meter.

Therefore, always use the same light meter for all measurements, or make comparisons between the different light meters.

2.2 Measurement site

There are a number of requirements on the location of both the analyser and the emitters and receivers.

Analyser:

The operating conditions specified in the manual must be met. These include

- Power supply 115 / 230 VAC, 110 W. If necessary, a UPS may have to be used to give stable and reliable power to the instrument.
- Operating temperature 5-30° C (USEPA equiv. 20-30° C).
- Relative humidity 0-80 %. The environment must be non-condensing at all times.
- No vibrations or other mechanical interferences.
- Environment free from dust.

If necessary, the analyser may have to be installed in an air-conditioned cabinet, certifying the temperature and humidity requirements, or with an dry air or nitrogen purge system, where a non-condensing environment can not be guaranteed.

Emitter and receiver:

Always follow the instructions given in the manuals for the emitters and receivers and power supplies.

- Both the emitter and the receiver must be installed on a firm base, minimizing any temperature induced movements. Steel and wooden constructions must be avoided. Instead, concrete constructions should be used. Steel brackets can however be used as a “shelf” when affixed directly to concrete, but preferably shaded or insulated to avoid effects from sun and heat radiations. If the base is not firm enough, an optional light optimiser LO 110/LO 150 can be installed in the emitter and/or the receiver. This device will guarantee optimum alignment all the time.
- The power lines should deliver reliable and stable voltage to the lamp power supply. If necessary, a UPS should be used to guarantee the power supply.
- The receivers may have to be equipped with window and mirror heaters in order to avoid condensation and/or ice build-up on the optical components, preventing light from reaching the analyser. This will also increase the life time of the mirror.

2.3 Path lengths

The table below summarises path lengths that can be used for different gases.

The detection limit is roughly inversely proportional to the path length,

$$C_0 \sim \frac{1}{L}$$

Table 2.1: Recommended path lengths for different emitter/receiver types and gases. Lengths are given in metres.

Gases	ER 110	ER 150	ER 120/130 [*]	RE 130
NH ₃	100-200	100-200	100-200	see emitter
NO	100-200	100-250	100-200	see emitter
Other gases	300-500	300-800	300-500	see emitter
Hydrocarbons with high resolution grating	250-500	250-600	N/A	see emitter

^{*}Optical path length, equal to 2 times the distance to retro-reflector

In areas where heavy fog is expected, the shortest recommended path lengths should be used in order to allow measurements also during fog events.

2.4 Measurement time

The selection of measurement time depends on the desired detection limit, and on the total time available to complete an entire measurement cycle. The detection limits are roughly proportional to the inverse of the square root of the measurement time:

$$C_0 \sim \frac{1}{\sqrt{t}}$$

Example: 4 x measurement time => 0.5 x LDL (lowest detection limit)

If there are no special requirements on detection limits, or if the path length is not either very long or very short, it is recommended to measure hydrocarbons like benzene, toluene etc. for 120 s, NO and NH₃ for 45 s, and other gases for 30 s. Using more than one path, it may be necessary to use shorter measurement times to achieve a reasonable total cycle time.

2.5 Temperature and pressure correction

The analyser always measure the actual gas concentration in weight (i.e. number of molecules) per volume unit. If desired, this concentration can be recalculated to standard temperature and pressure conditions (NTP 0/20/25 °C, 101.3 kPa) using proper corrections.

NTP correction is enabled in the **Measurement setup** menu. Once enabled, the actual temperature and pressure can be specified in the **Path specifications** menu. The values can either be assumed constant, giving a static correction, or they can be read from a data-logger, giving a dynamic correction of the gas concentrations. If corrections are used at all, the latter strategy is recommended. The temperature or pressure correction can be disabled individually by setting the correction value to constant 0 °C and 101.3 kPa respectively.

If a correction is in use based on a fixed pressure value, please note that the average ambient pressure is not always 101.3 kPa. This value is valid at the sea level. The average pressure drops by about 0.1 kPa for each 8 m. E.g., at the height of 500 m above the sea level, the average pressure is $101.3 - 0.1 \cdot 500/8$ kPa = 95.1 kPa.

Example: Temperature correction

$$100 \cdot \frac{273 + 100}{273} = 309,6$$

$$100 \cdot \frac{273 + 120}{273} = 317$$

Example: Pressure correction

$$100 \cdot \frac{101,32}{102} = 99,3$$

$$100 \cdot \frac{101,32}{101} = 100,3$$

2.6 Special fence-line application precautions

In a fence-line application, the analyser is monitoring fugitive emissions from industrial sites like chemical production facilities. The ambient air in these areas can contain high concentrations of gases normally not present in ambient air. In some cases, these gases show spectral interferences with the gases being measured by the analyser, thereby affecting the measurement performance. Special attention and consideration is therefore required when planning and installing these kind of systems.

When planning for and installing a fence-line monitoring system, the following should be considered:

- In some cases, it is known from the beginning that there are high pollution levels of specific substances. This knowledge can be based on e.g. the production processes in use. The knowledge should be passed on to Opsis AB before the instrument is actually produced. It may then be possible to compensate for these interferences by making a tailor-made calibration and evaluation procedure for the specific instrument.
- In other cases, interferences show up first as the instrument starts measuring. Then, the problem has to be dealt with on site by Opsis by making individual changes in the evaluation procedure of the gases being measured. This can be an extended process, since it takes time to verify the correct behaviour of the instrument.

Unlike other applications, fence-line monitoring may require individual adoption of the evaluation procedures of the instrument, as indicated above. The time for installation and start-up of this kind of system may therefore be longer than normally.

2.7 Using the site data report sheet

A site data report sheet has been prepared for convenient registration of basic measurement data. The sheet is found in Figure 1.2 in this manual.

Path lengths, UV filters (UF 220, UF 225), lamp types, light intensities, measurement times and other data are all used in various QA/QC procedures, and should therefore be carefully established at the time of installation.

Establishing the function of the hardware is the basis for quality assurance. The hardware should be checked frequently, in order to capture errors at an early stage, thereby minimizing possible downtime. Many of the steps described below can be monitored remotely through telemetry, without involving any site visits. A hardware function report sheet can be found in Figure 1.2 in this manual. Comments to this report can be found in section 3.8.

3.1 Light levels

The variations in *light intensity* for a measurement path should be kept at a minimum, since lower light increase the measurement noise. Always try to maintain the intensities achieved during the initial installation of the system, which should correspond to the maximum obtainable levels. The light intensity readings may vary from light meter to light meter. Therefore, always try to use the same light meter for all measurements, or make comparisons between the light meters and translate the achieved light intensity to a standard scale.

The analyser reports a *light level* value for each measurement of a gas concentration. The light level is a value from 0 to 100 %, where 0 % corresponds to no light and 100 % to “full” light. The percentage value is *not* a direct measurement of the light intensity in lux on a path, but an indication of the amount of internal amplification on the detector (usually a photo-multiplier tube). Since the light level depends on the internal amplification of the electronics, different light levels may be reported for different analysers connected to paths transmitting the same light intensity in lux.

The light level is still a useful tool for monitoring the state of the emitter and receiver alignments. In general terms, the following should apply:

- The daily variations should be as small as possible.
- Light levels should be kept at levels where the data quality is accepted (see sections 4.4 and 5.3)

The light level does not only depend on the alignment of the emitter and receiver, but also on e.g. meteorological conditions. Rain, fog etc. may temporarily lower the light level considerably. Drops in light levels due to meteorological conditions is a natural part of the light level characteristics, and should not be mixed with variations caused by phenomenon that can be eliminated by adjusting the emitter or receiver.

3.1.1 Light optimiser LO 110/LO 150

A light optimiser is used to automatically and regularly adjust the alignment of a measurement path. It is a convenient way to optimise the light intensity on the path, specially if the foundation of the emitter or receiver is moving noticeably. An unstable installation or temperature variations can affect the alignment of the light beam.

The light optimisers LO 110/LO 150 are designed for the emitters EM 110/EM 150 and the receivers RE 110/RE 150. The mirror box MB 300 can also be equipped with a light optimiser. Any number of paths connected to a single analyser through a multiplexer can be equipped with light optimisers.

For site requirements for the emitter and the receiver, please refer to the ER 110/ER 150 User's Manual and Installation Guidelines.

3.1.2 Selecting gases and studying light levels

The light levels are individual for each path and each gas. However, since the spectrum is continuous, it is usually sufficient to study only two light levels per path, one at each end of the spectrum. Choose the gases as follows:

- If NO or NH₃ is measured, the light level for one of these gases should be studied.
- If one or more hydrocarbons are measured, the light level for one of them, typically benzene or toluene, should be studied.

If none or only one of the rules above apply, then select one or two other gases if available, typically SO₂ or NO₂.

The light levels are conveniently monitored by collecting and presenting measurement data using Ophis software packages like the Enviman ComVisioner or Reporter. Automatic report printouts and alarms can easily be implemented in these programs.

Measurement data can be collected in two ways, either transferring every measurement point, or transferring averages calculated in the analyser. When calculating averages, however, some individual measurement points may be filtered out because they are bad. Since these points might be the ones with bad light conditions, it is better to collect all measurement points, important data may otherwise be lost. See Chapter 5, Data validation, for more information.

3.1.3 Allowed variations

Usually, it is not possible to completely eliminate variations. It is however hard to give any absolute values within which the light level may vary. The light attenuation test described in section 4.4 should give a good indication of reasonable light limits. Still, one should always try to find the maximum light level, and minimize the variations.

3.1.4 Daily variations

Daily, periodic variations typically occur due to movement of the emitter or receiver bases. A concrete construction is the best and only recommended base for the equipment. Frequently, these variations are due to the sun heating the bases.

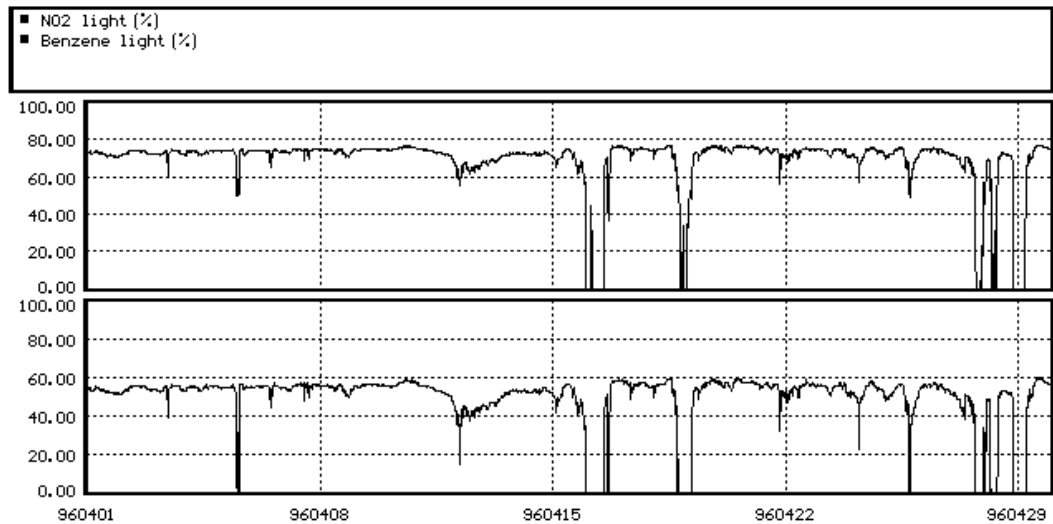


Figure 3.1. Example of a light level study. The light levels behave steadily, with neither any obvious periodic behaviour, nor any long-term drift. The irregular drops to zero light were due to meteorological conditions, in this case severe snowfall.

Having ruled out variations due to meteorological conditions, daily variations are minimized as follows:

- The light spot illuminating the area around the receiver should hit the receiver centrally. If not, small variations in direction may lead to large drops in light intensity. Make sure the emitter is focused correctly, and adjust the alignment if necessary. Please refer to the manual for details.
- Also make sure that the focusing and alignment of the receiver is correct. Please refer to the manual for details.
- Moisture can cover the receiver mirrors or windows due to temperature and air humidity. Mirror and window heaters can be installed if this is a frequent problem.
- If neither of the above changes help, the emitter and/or receiver should be relocated, or automatic light optimisers may be installed. Please consult the Opsis representative for advice .

If an emitter or a receiver is adjusted, always compare the obtained light intensity with the original one from the initial installation. Keep a record of the new intensities.

3.1.5 Slow changes

A gradual change, normally a drop, in light intensity is usually only noticeable when studying weeks or months of data. There may be several reasons for this drop:

- Deterioration of the lamp. When the lamp gets old, the intensity in the deep-UV part of the emitted spectrum will start to drop. This is noticed as a larger drop in light levels for deep-UV gases like NO or benzene than for normal-UV or visible gases like SO₂ or NO₂. The lamp then needs to be replaced. If the recommended interval is followed, this problem should not occur.
- Slow base movements. This is typically revealed as a drop in intensity for all gases at the same time. The change is due to slow movements in the base structures induced by temperature or ground settling. Perform the adjustments described under Daily variations. One or a few of these adjustments per year are normal. If adjustments are required as often as every month, a relocation of the emitter or receiver, or installation of automatic light optimisers, should be considered.
- Dust and other pollution problems. Optical components like windows, UV filters and mirrors being exposed to the environment may deteriorate in various ways. Check the condition of these components as described in Section 3.4, Site inspection and data backup. Following the recommended inspection interval, the problem will disappear by routine maintenance before it starts affecting the measurement performance.

Since any of the above reasons can occur in any combination, one should check all of them when visiting the measurement site.

When adjusting the emitter or receiver, always compare the obtained light intensities with the ones from the original installation, and make a note of the new intensities achieved.

3.2 System check

A system check is performed in the analyser to check the function of the spectrometer and the electronics. A successfully completed system check ensures that the spectra recorded by the opto-analyser are reasonable.

A system check is performed by aborting the measurements by pressing [Esc] on the analyser keyboard, followed by [F5] to start the check.

The analyser will run through a number of checks for

- rotating disk stability,
- grating positioning, and
- detection system.

To complete the check, light from e.g. one of the measurement paths must enter the spectrometer.

Each step of the test should normally report **Ok** as a result. A message “*Permanent change of P4?*” will occur after having completed the test. The parameter P4 corresponds to the accuracy of the grating positioning. If the P4 result was reported as **Ok**, then P4 should *not* be permanently changed, press **[N]** to answer no to the question.

If the P4 test failed but the P3 test was ok, then make a note of the value reported as P4. Run another system check, without making a permanent change of P4, i.e. answer **[N]** to the question. If the second test shows about the same value (± 10) for P4 as the first one, and P3 is still ok, then make the permanent change by pressing **[Y]** as the question is prompted. Run a third system check to verify that now also P4 is ok.

Note that P4 *must not* be changed if P3 is incorrect. If P3 is out of range, contact the Opsis representative. If P1, P2 or P5 are out of ranges, repeat the system check to confirm the readings. Refer to the troubleshooting section in the hardware manual, and contact the Opsis representative.

After having successfully completed the system check, exit to the root menu and resume measurements by pressing **[F4]**.

A system check may be performed automatically as a part of an automatic reference or gas calibration, as described in the software manual. An automatic system check will not make any corrections to P4, but the result can be reported by using the ‘system check alarm flag’. If the check fails, the flag will be raised. This can be reported as a channel in a built-in datalogger, giving the possibility to have an automatic alarm set in the data acquisition software.

There is also a possibility to perform the system check through a modem, using the ‘remote session’ function in the ComVision or ComVisioner software.

ComVision (DOS) software:

Go into the **Service** menu in ComVisioner, and move the scroll bar to the station to call. Press **[Alt][F1]** (instead of just **[F1]**). After having established contact, the last option in the menu will be ‘Remote session’. Select this option.

From now on, everything shown on the screen will be a copy of the analyser’s screen, and everything typed on the keyboard will be sent to the analyser as if it was typed on the keyboard there (with exception of the **[Tab]** key, see below). Now, proceed just as described on the previous page, pressing **[Esc]**, starting the system check by pressing **[F5]** etc. The results of the system check will be presented on the screen.

Remember that the **[Esc]** key in the ComVision computer corresponds to the **[Esc]** key in the analyser. After having completed the system check and brought the analyser back to measurement mode, press the **[Tab]** key to terminate the remote session. Now, the communication can be terminated by pressing the **[Esc]** key in ComVision, since there is no longer any relation to the keyboard in the analyser.

Enviman Comvisioner software:

Go to the “Service” menu, choose the **[Communication]** button (to the far right on the top menu) . Select station, and press **[OK]**. When connection has been established, the **[Remote Session]** button (to the far right on the top menu) will be highlighted. Press the **[Remote Session]** button , and the analysers screen will be shown. From now on , everything typed on the keyboard will be sent to the analyser. Press **[F5]** in the analysers Main Menu to start a System Check. After completing the System Check, press the **[Stop]** button on the windows top menu to stop the remote session. Press the **[Stop]** button one more time to disconnect .

The remote session function should be used with great care. It is indeed possible to make changes in the analyser e.g. so that the communication line will be lost. It is then no longer possible to call the analyser again, and a site visit may be required to get the opto-analyser back into measurement mode again.

3.3 Disk space and analyser clock

All measurement data produced by the analyser is stored on the hard disk. The available disk space will therefore decrease as more measurements are stored. The current disk space is shown in measurement mode on the top row. The size is given in MB (mega-bytes).

It is advisable to have at least a few MB of available disk space on the hard disk. By studying the decay of the disk space, it is possible to estimate when the hard disk will be filled up, and thus when old data files need to be removed.

Old data files are removed in the **Data presentation** menu. Select either gas data or datalogger data, pick a datafile and choose **Delete data** in the **Output window**. Once a datafile has been removed, it cannot be recovered.

It may be advisable to make backups of datafiles, either as they are produced, or at least before they are removed from the hard disk. The backup procedure is described in the section 3.4, Site inspection and data backup.

The analyser clock is displayed next to the disk space value. It is essential that the clock is correct, since all measurement data is stored with time information from this clock. The clock must therefore be corrected if there is a tendency to drift in time. If required, the clock is set under **Station setup** in the **Installation** menu. If the Opsis Enviman Com-Visioner is used for Data Aquisition , the function **Automatic time synchronization (System setup/Stations/Communication)** can be used to let the Central Station computer control the time of all Opsis analysers in the monitoring network

Disk space and analyser clock is most easily checked together with performing the system check as described above. Note that it is possible to do all this remotely using dial-up communication - site visits are not required for this purpose only.

3.4 Site inspection and data backup

The measurement site should be visited regularly to visually make sure that the system is operating as expected, without any external interferences.

- Check the temperature at the analyser location. It should be within the operating limits specified in the manual.
- If the environment is dusty, check the filters in front of the fans on the analyser, and clean or replace them if necessary. Instructions for doing this can be found in the hardware manual.
- Abort measurement mode, and check the light from the measurement paths. Since this may take some time, the analyser should be ‘parked’ in the **Station setup** menu. If more than one path is used, each path should be checked by manually moving the multiplexer to the correct position. Check:
 - the light intensity by using an LM 010 lux meter. The light level should not have changed considerably since last measurement. Always compare the light level with the initial values recorded at installation. Check and adjust the beam if the light intensity has dropped, see below.
 - the beam profile appearing when the fibre end is held 10-15 cm from a white piece of paper. The profile should be smooth and circular, without any dark spots or rings inside it. A non-uniform profile appears due to modes being built up inside the fibre. The profile can be smoothened by ‘scrambling’ the modes. This is done by gently bending the fibre close to the receiver end (or multiplexer end) until the pattern disappears.
- For each measurement path, check the condition of the emitter and receiver mirrors. They should *not* be grayish, covered by dust, or have any damage to the surface. Loose dust can be blown off gently. Do *not* try to physically clean the surface, since this will damage the thin protective MgF_2 layer. The mirrors should be replaced when too much light is lost due to deterioration of the reflective surface.
- Check the front windows of the emitters and receivers. They can be cleaned with a soft cloth, if necessary with the help of water or pure alcohol. Also clean all fibre ends and UV-filters using a clean, soft and dry cloth.

Please refer to the emitter/receiver manuals for more information on maintenance. Resume measurements when finished, or proceed with the backup procedure below.

- If desired, make backups of data files. This is done from the **Data presentation** menu. Select either gas data or logger data, choose a file, and activate **Backup utility** in the **Output** window. Follow the instructions on the screen. Resume measurements when finished.

3.5 Wavelength precision

A wavelength precision test verifies that the wavelength range seen by the analyser is identical to the range for which it was manufactured. If not, the positioning can be adjusted.

The spectrum recorded in the spectrometer is divided into 1000 channels. By moving the grating, different wavelength windows can be detected. The accuracy of the grating positioning must be within ± 10 channels for the spectral evaluation to complete properly.

When the analyser was manufactured, a mercury spectrum for most of the measured gases was recorded. The precision of the grating positioning can be checked by recording a new mercury spectrum, and compare it with the old one.

Depending on the gases measured by the analyser, there may only be a few that have mercury spectra. An alternative procedure for checking the wavelength precision is then the **View residuals** function. Please refer to section 3.5.3 for a description.

3.5.1 Hardware requirements

To complete a wavelength precision test, the following equipment is needed:

- Wavelength check lamp CA 004.
- Fibre optic cable between the mercury lamp and the analyser.

3.5.2 Performance

Proceed as follows to perform a wavelength precision test:

1. Exit measurement mode, press **[F3]** for calibration procedures, **[F6]** for advanced calibration procedures, and **[F1]** for the Check wavelength precision function. A list of the measured gases is presented, together with range information and a column indicating if a mercury reference is available. Several gases can have the same range indication. They are then evaluated in the same wavelength region, and are thus using the same mercury spectrum. It is only possible to check the precision for the gases having a mercury reference available.
2. Connect the CA 004 cable to the multiplexer port on the analyser.
3. Connect the opto-fibre between the CA 004 and the analyser.
4. Switch on the CA 004 by pressing the black button gently. The green LED on the aluminum should give light.
5. Use the arrow and **[Space]** keys to select all gases.

6. Press **[Enter]**. Specify the number of seconds the spectrum should be recorded, 10 s is usually sufficient, and press **[Enter]** again. The mercury spectrum will now be recorded.
7. When the recording of the mercury spectrum is finished, the result is presented in two ways. First as a graph, where the original spectrum is shown together with the new one. Secondly, when pressing **[Esc]**, the channel shift is calculated and presented together with an accuracy factor. The accuracy factor is the correlation between the two spectra within an interval of ± 50 channels. The factor can be between 0 and 1, and is expressed in %. Normally the accuracy is 90 % or higher, but depending on the gas (wavelength) studied, it can be significantly lower, but still acceptable. The factor is used to confirm that the comparison is made with the correct mercury spectrum, i.e. the mercury lamp functions well and the analyser operates correctly.

The channel shift must *not* exceed ± 10 channels. The result will otherwise be a negative deviation when the component is evaluated. If necessary, however, a correction of the shift can be made. This correction should be made if the shift is more than 5 channels. It can only be done when the shift is less than 50 channels, and when the accuracy is better than 50 %.
8. If a correction is desired, press **[Y]**. Otherwise, press **[Enter]** or **[N]**. Always repeat the wavelength check when an adjustment has been made.

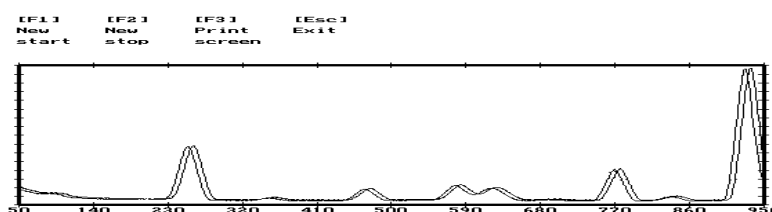


Figure 3.2. A check of the grating precision of ozone, using mercury spectrum. New start and stop channels can be selected with the **[F1]** and **[F2]** keys. **[F3]** is used when a print-out is desired.

If the result of the wavelength check (possibly after having repeated the check after an adjustment) is not within ± 10 channels contact the Opsis representative for further assistance.

It is possible to make a manual adjustment of the wavelength by selecting gases, and then pressing **[A]**. This is an advanced option which can be used either if there is no spectrum available, or to override the result of the comparison with the pre-recorded spectrum. Do not use this option unless specifically instructed to.

3.5.3 Alternative procedure: View residuals

In some cases, there are no mercury spectra available for some or even a majority of the gases measured by the analyser. The reason for this is then that mercury simply has no

emission lines in the selected wavelength window (e.g. IR gases such as HCl and H₂O and UV gases such as NO and NH₃).

The only option to check the wavelength precision is then to use an actual measurement spectrum, and use the absorption features in this to calculate the shift.

Proceed as follows to check the channel shift through **View residuals**:

1. Exit measurement mode, press **[F3]** for calibration procedures, **[F6]** for advanced calibration procedures and then **[F3]** for the **View residuals** function. Select the gases *not* checked by the mercury lamp by moving the cursor to the desired row and pressing **[Space]**. Press **[Enter]** to start the evaluation.
2. For each gas selected, a list of the ten most recent spectra (measurements) will be displayed. Generally, for this purpose it does not matter which one of them to select. Just press **[Enter]** with the cursor on the first row. The spectrum is now evaluated again, just as it was during the normal measurement. However, the presentation is different. Please refer to the software manual for a description.
3. Press **[Esc]** to exit from the graphical presentation. An “initial shift” value is displayed together with a “shift” value. The “initial shift” is to be reported as the actual channel shift, and should always be less than ± 10 channels. Please note that the “initial shift” value will not be representative if the spectrum corresponds to a low concentration below the detection limit. Then, the spectral information in will not be sufficient for finding any spectral features to lock on. The channel shift may then slide to either +10 or -10, not necessarily being an indication of a malfunction of the instrument. If the calculated concentration is below the calculated deviation, the channel shift is not reliable, and the current spectrum cannot be used for evaluating the shift.

If the spectrum corresponds to a too low concentration, another spectrum has to be chosen from the list. If none of the available spectra show a high enough concentration, then the test will have to be postponed until the ambient air concentration is higher.

Important: *View residuals will only work if the analyser evaluates a concentration noticeable above the calculated deviation.*

If a mercury spectrum is available, use this to check the channel shift. **View residuals** is just the second best alternative since the result not only depends on the grating precision, but potentially also on the evaluation procedure. Therefore, only use **View residuals** for gases where mercury spectra are not available.

3.6 Lamp change

When a lamp is aged, the emission in the UV part of the spectrum is deteriorating. This effect is noticeable when measuring gases in the very low UV part of the spectrum. These gases are e.g. NO, NH₃, and hydrocarbons like benzene and toluene.

Therefore, the lamp needs to be replaced on a regular basis. However, it is not possible to determine the ageing by looking at the light intensity (in lux) or the “light level” (in %), since the ageing only affects the very lowest part of the UV spectrum. The recommended interval for replacement, 6 months, is based on experience.

The procedure for exchanging a lamp can be found in the emitter/receiver manuals. Please study the manual and the safety precautions carefully.

- Make sure that the power supply is disconnected before starting to work on the lamp.
- The high-pressure bulb can explode if not handled with great care. Therefore always wear protective goggles, and cover your skin as far as possible.
- The old lamp is very hot immediately after being switched off. Wait some time before starting to replace it.
- Do not remove the protective cover from the new lamp before it is in place.
- Never touch the lamp glass.
- Put the plastic cover around the bulb of the old lamp, and place the lamp in the lamp box. To avoid accidents, safely crush the lamp bulb before disposal.

Procedures for adjusting the new lamp can also be found in the emitter/receiver manuals. Make proper notes of when each lamp has been replaced, and keep track of the age of the lamps in use so that changes can take place before the ageing starts to influence the measurement results.

3.7 Analyser overhaul

It is recommended to have the analyser checked on a regular basis by an Opsis representative certified for doing overhauls. The representative makes extended checks and tests of the instrument. This includes e.g. mechanics, optics, computer and other electronics, and measurement performance.

3.8 Using the hardware function report sheet

A report sheet for hardware function can be found in Figure 1.3 in this manual. Since different procedures are to be performed on different intervals, some parts of the sheet will not have to be filled in every time some hardware functions are checked.

Measurement performance 4

Establishing the hardware function is not sufficient to verify the proper operation of the instrument. It is also necessary to check the measurement performance, i.e. to verify that the system responds correctly to gases of known concentrations. The measurement performance is assured by using a number of procedures, described below.

4.1 Reference check

The reference is the name of the raw lamp spectrum, without any absorption lines, with which the measured spectrum is divided by in the evaluation process. This spectrum needs to be updated to compensate for changes in the analyser spectrometer and electronics. Taking a new reference minimizes the measurement noise.

A reference check includes a re-recording of the lamp spectrum. In most cases, it is not possible to use the same lamp as is being used in the path. Instead, a special calibration lamp is used during the recording. This is possible since all lamps of the same type emit the same spectrum.

4.1.1 Hardware requirements

The following Opsi hardware is required to perform a reference check:

- Wavelength check lamp CA 004 for wavelength precision test.
- Calibration bench CB 100 and two RE 060 units.
- Lamp unit CA 150, provided with the correct lamp. The unit should be equipped with a “blue filter” if it is to be used with a OF 60R fibre.
- UF 215/220 filter, if filter is used for normal measurements.
- Power supply PS 150.
- Fibre optic cables, two pieces, 3 to 5 metres each, type depending on gas.

- Light meter LM 010. If possible, use the same light meter for all procedures where the light intensity is to be established.

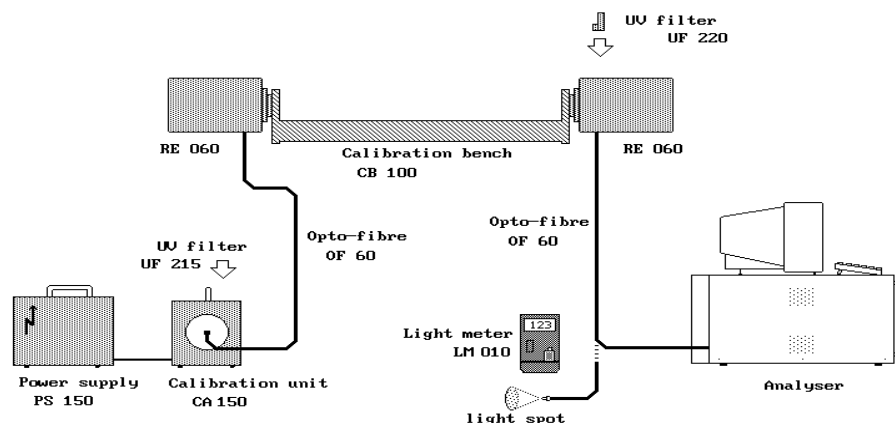


Figure 4.1. Standard setup for the reference check. Either of the UV filters, but never both, are required if a UV filter is used for normal measurements.

4.1.2 Initial preparations

Some basic reference check parameters and the reference recording time have to be set before a reference check can be performed. Since these parameters normally never are changed they are set only once, typically during the installation of the system.

Go to the **Installation** menu, and select **Calibration setup**. Go to **Calibration path setup**, and set the following parameters for path No. 1:

- | | |
|-----------------|--------|
| - Physical path | 1 |
| - Path control | Manual |

The other parameters are not used in a manual reference check.

Then go to the **Reference calibration setup** menu. For each gas, set

- | | |
|--------------------|---|
| - Active | Yes |
| - Calibration path | 1 |
| - Measurement time | 180 + No. of seconds for normal measurement |

The other parameters are not used in a manual reference check.

There is a possibility to fully automatize the reference check procedure. Information on how to do this can be found in the analyser software manual. The description below does not cover the automatic procedure.

4.1.3 Performance

The procedure for a manual reference check is described below. The reference check may be automated, but this is not described in this manual. The step numbers correspond to the numbers found in the different parts of the Reference check report sheet, as shown in Figure 1.4.

1. Check in the Site data report the lamp type and fibre optic cable that is being used in the path where the gas to check is measured. Also check if a UF 220 or UF 225 filter is used for this gas. Set up the equipment as indicated in Figure 4.1, with the correct type of lamp and fibre, and a UV-filter if used. Switch on the lamp and wait at least 30 minutes for it to stabilize. If different lamp and fibre types are used for different gases, then first run a reference check for all gases using the first type, and then a check for the other gases.
2. Perform a *System check* as described in section 3.2 using the light from a measurement path. If the system check fails, do not proceed with the reference check.
3. Perform the Wavelength precision test as described in section 3.5. Do not proceed with the reference check unless the analyser passes this test.
Note that some gases in the low UV part of the spectra, such as toluene, may report an accuracy below 50 %. However, if the shift is within ± 5 channels, you can proceed.
4. Check the light spot from the reference check setup. The light intensity should be maximized. Also, hold the fibre 10-15 cm from a white piece of paper, and make sure that the light spot is smooth without any dark spots or rings. If not, gently bend the fibre close to the *receiver* end, until the pattern disappears. It may also be necessary to readjust the CB 100 setup alignment. Connect the light from the CB 100 setup, perform a second system check, and make sure that the P3 test passes. If not, the light intensity is too high. Then, defocus the emitter mirror, and repeat the entire step 4.
5. Measurement data from a calibration check must not be mixed with normal measurement data. To avoid this, you should first disconnect any communication line like a telephone connection. Secondly, change the system name to one not being used otherwise. The extension could e.g. be .REF. The system name is changed in the **Station setup** menu, accessed through the **Installation** menu.
- 6a. A number of test measurements will be made using the first measurement path. Go to the **Change span/offset** menu under **Calibrations**, make a note of the initial offset value for path one for the gases to be checked, and set these offsets to zero.
- 6b. If a multiplexer is being used, then deactivate it by setting **Multiplexer type** to **None** in the **Measurement setup** menu.

- 6c. Go to **Measurement time**, make a note of the time for each gas on path 1, and set the time to the longest measurement time being used on any path. (Not applicable if the system uses only one path.) Set the measurement time for the gases *not* being checked to zero.
- 6d. Connect the fibre from the calibration bench to the analyser, and bring it back to measurement mode. Let the analyser measure for three to four complete cycles, and note the concentrations, deviations and light levels being reported.
- 6e. Go to **Calibration** and select **Reference calibration**. Set **Skip reference check** to **Yes**, and tick all gases currently being under investigation. Then select **Start calibration**. Proceed through the reference recording for all gases. There is now a new reference spectrum for each gas.
- 6f. Go back to measurement mode and complete another three to four cycles, making note of the results. These are measurements using the new reference spectra.
- 6g. Study the deviations for each gas obtained with the old and the new reference spectra. If the new deviations are of equal or smaller range, then the new reference should be used. The old reference should therefore not be restored. However, if the deviations have increased, or the concentrations changed drastically, the new reference actually made the analyser worse. This should normally not occur, but might happen if something is wrong with the reference check setup. The new reference should then not be used. Instead, restore the old one by going to the **Restore reference** function in the **Calibration** menu. Select the gas, and press [P] to restore the previous (i.e. old) spectrum.
- 7. Restore the correct multiplexer type, and reset the measurement times to the original ones. Then reconnect the normal measurement fibre, and let the analyser measure for two or three full cycles. Carefully study the obtained results.
- 8. If all measurement results are found reasonable, then the new references are working as expected. Now, restore the original system name, and reconnect the communication line(s). The system is now fully ready to operate under normal conditions using the new references.

Note that a reference check is *not* used to find a proper offset value - see section 4.2.

4.2 Multipoint span/offset calibration

During dynamic calibrations, i.e. span/offset calibrations, the accuracy of the analyser is checked by measuring a standard gas of known concentration. The instrument can then be fine-tuned by using a factor to multiply and/or increment measurement results.

The span and the offset factors are taken into account in the very last step in the evaluation as arithmetical adjustments of the calculated results and they do not affect the fundamental evaluation process. The span factor is used to adjust the instrument sensitivity and should ideally be 1.000, but may be any value that gives the instrument a correct reading according to a calibration standard. The offset factor is used to adjust the deviation from the zero line when measuring zero gas. Ideally it should be 0.000. The span factor has no dimen-

sion, while the offset factor has the same unit as defined in the **Measurement setup** menu; see the Analyser software manual, section 2.2.3.

A multipoint span calibration consists of at least six roughly equally spaced calibration points, including the zero point, covering at least 80 % of the measurement range.

From the physical relation on which the evaluation is based, it follows that the absorption is dependent on both the gas concentration and the monitoring path length. Physically, the light absorption for a specific component is dependent on the amount of molecules between the light source and the receiver. It is insignificant whether there is a high concentration over a short path or a low concentration over a longer path. As long as the factor (concentration C multiplied by the path length L) is constant, the light absorption will remain the same.

As a consequence, the expression ($L \times C$) is important when calibrating the analyser. The unit is $\mu\text{g}/\text{m}^2$ or $\text{ppm} \times \text{m}$, dependent on the selected measurement unit. The factor can be interpreted as the optical density. In order to cover the full measurement range the optical density should be in the same order of magnitude when span calibrating as when measuring the ambient air.

The relation is illustrated in the following example.

In a certain application the monitoring path length is 400 metres. The measurement range for SO_2 is 0 to 500 ppb. The maximum optical density is then given by

$$500 \text{ ppb} \times 400 \text{ metres} = 200 \text{ ppm} \times \text{m}.$$

Using a standard gas concentration of 1000 ppm, the calibration path is calculated to 0.2 metres, since

$$1000 \text{ ppm} \times 0.2 \text{ metres} = 200 \text{ ppm} \times \text{m}.$$

By using shorter calibration paths, or by diluting the gas standard to lower concentrations, several measurement points within the measurement range are obtained.

In the example the following relation was used:

$$L \times C = L_c \times C_c \quad (4.1)$$

L is the monitoring path length, C is the upper range limit, L_c is the calibration cell length, and C_c is the calibration gas concentration.

A multipoint span calibration of an open-path instrument can be performed

- *either* by varying C_c , i.e. by diluting the standard gas concentration with zero air
- *or* by varying L_c , i.e. by using calibration cells with different lengths.

The latter method has several advantages. The most important one is that no dilution system and no zero air supply is required, since the entire calibration is performed with one standard gas concentration only. Several sources of error, including the flow meters, can thus be excluded. The following description is therefore based on this method.

By using three calibration cells with the length ratio of approximately 1:2:4 up to eight calibration points can be obtained, since the cells can be inserted more than one at a time in the CB 100 setup. Knowing the standard gas concentration the total calibration length $L_c = L_{c1} + L_{c2} + L_{c3}$ for checking the upper range limit of the analyser is calculated from

$$L_c = L \frac{C}{C_c} \quad (4.2)$$

When span calibrating the analyser based on the former method the following should be considered. In order to obtain the test gas concentrations C_c the calibration gas concentration C_o has to be accurately diluted. A flow of zero air is added to the original gas concentration, and the mixture should be passed through a mixing chamber to insure a homogeneous concentration in the calibration cell.

The dilution ratio R must be accurately known for each calibration point. Hence the two flow rates for the calibration gas F_O respective the zero air F_D must be accurately measured to better than 2%. To help insure accurate flow measurements, the two flow meters should be of the same general type and one should be standardized against the other. The dilution ratio is calculated as the flow of the original concentration (F_O) divided by the total flow ($F_O + F_D$):

$$R = \frac{F_O}{F_O + F_D} \quad (4.3)$$

With stable, high resolution flow meters and careful work, R should be accurate to better than 1 %.

4.2.1 Hardware requirements

To perform a dynamic multipoint span/offset calibration of the analyser, the following Op-sis hardware is required:

- Wavelength check lamp CA 004.
- Light meter LM 010. If possible, use the same light meter for all procedures where the light intensity is to be established.
- Calibration setup bench CB 100 and two RE 060 units.
- Calibration unit CA 150, together with power supply PS 150. The unit should be equipped with a “blue filter” if it is to be used with an OF 60R fibre.

- Correct type of xenon lamp, depending on the gas, see the Site data report.
- Fibre-optic cable, two pieces 3 to 5 metres each. The type depends on the gas, see the Site data report.
- Calibration cell CC 001-X, where X stands for length in millimetres. Appropriate lengths are calculated from equation [4.8] where the standard gas concentration C_c is known. At least 80% of the measurement range $L \times C$ should be covered. Available cell lengths are 10, 15, 40, 100, 250, 500, and 900 mm.
- UV filter GG 400 - optional, but not required, when NO_2 is calibrated.
- UV filter UF 215/220 - required only if a UV filter UF 220/225 is indicated for a specific gas in the Site data report. Only one filter should be used in the calibration setup.
- Calibration gas cylinders with concentrations as calculated from eqn. [4.1]. Please see section 1.4, Safety precautions, before handling any gases.

Please refer to the Figure 4.2 and Figure 4.3 for layout of the setups.

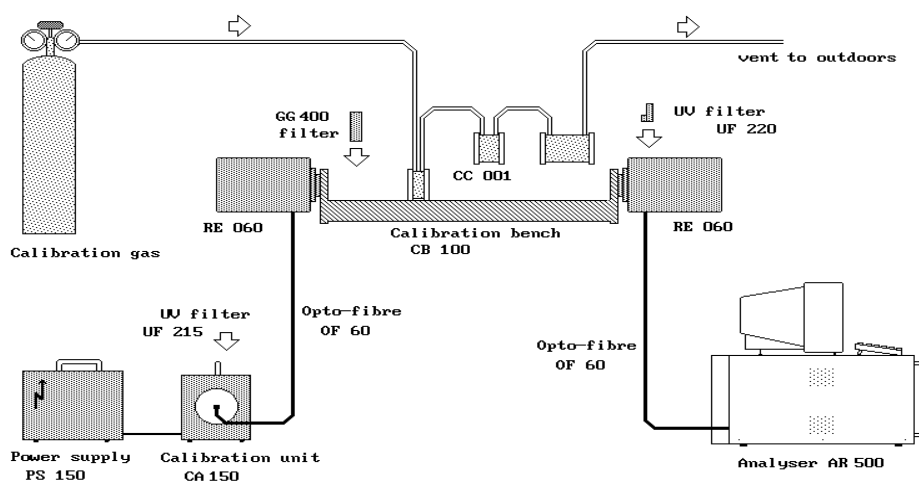


Figure 4.2. The setup for performing a dynamic, multipoint span calibration of gases available in cylinders, such as SO_2 and NO_2 . The GG 400 filter is optional for NO_2 calibrations only. If used it should then be inserted between the light source and the first calibration cell. Either of the UV filters, but not both, should be used if a UV filter is used for normal measurements for the gas being calibrated.

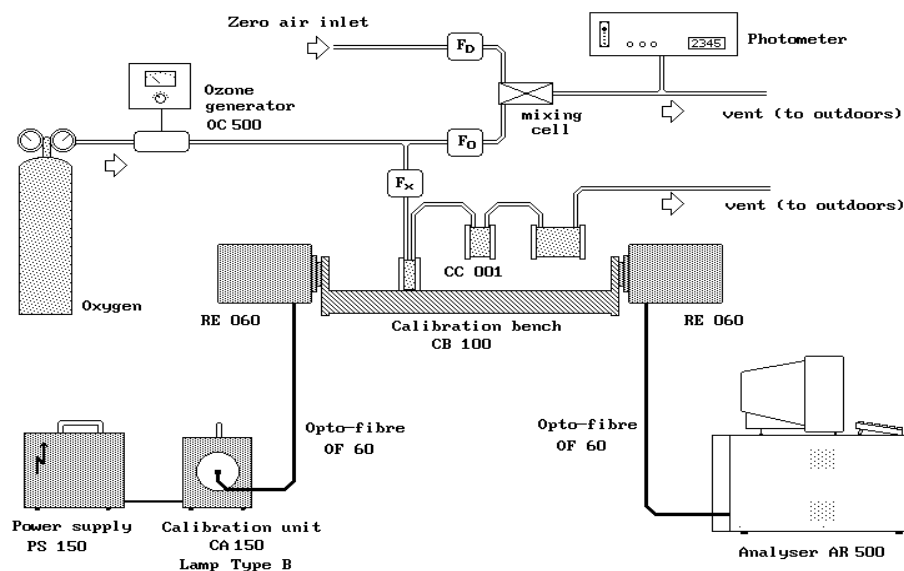


Figure 4.3. The ozone calibration setup based on the Opsis ozone generator OG 500. In order to dilute the ozone calibration concentrations to ambient levels for assay by the photometric instrument the flow rate ratio $F_O : F_D$ should be at least 1:100. The flow rate through the cell F_x is insignificant for the assay, however, it should be set between 200 and 500 cc/min. An easier solution is to use the Opsis ozone calibrator, OC 500.

4.2.2 Performance

1. It is recommended that a good record keeping system is established by the operator. A site log book and calibration data sheets should be maintained together with the instrument at the monitoring location. A multipoint span/offset calibration report sheet is found in Figure 1.5. The step numbers below correspond to the sections in this sheet.
2. Turn on the calibration lamp. Let the lamp stabilize for 30 minutes. Meanwhile, specify the calibration setup by recording cell lengths, temperature and pressure in the calibration cells, filter equipment and flow settings if applicable. Maximize the light intensity from the calibration bench. The light spot visible when holding the fibre end 10-15 cm from a white piece of paper should be smooth without any dark spots or rings in it. If not, gently bend the fibre close to the receiver side until the patterns disappear.
3. Abort the normal measurements. Note the measurement path length, ambient temperature and pressure, and light intensity (lux) and light level (%) on the path (average if more than one path). Readjust the calibration bench alignment if necessary. Go to the **Change span/offset** menu under **Calibration**, make a note of the existing span and offset values for path one, and set span to 1.0 and offset to 0.0. Go to the **Path specifications** menu under **Measurement setup**. The temperature correction for path 1 should be set to **Constant**, and the value should be the temperature in the cell, typically 20°C. The pressure correction should also be set to **Constant**, and the value to the cell pressure, typically 101.3 kPa. If NTP correction is not active, then activate it. Note that the path length should *not* be changed. The outside length should be kept.
4. Go to the **Measurement time** under **Measurement setup**, and make a note all times on path 1. Then change **Multiplexer type** to **None**.
5. Proceed with the preparations by setting the measurement time for the gas to 30 or 60 seconds. Since the analyser will be operating in normal measurement mode, and the calibration values should not be mixed with normal measurement values, the communication lines must be disconnected. In addition, the system name must be changed to a name not used for normal measurements. The extension could typically be .CAL.
6. Perform a System check according to section 3.2. Use the calibration bench light for this test. If P3 fails, the light intensity is too high. Defocus the emitter mirror, check the light spot, and repeat step 6. If the analyser still does not pass the check, do not proceed with the calibration.
7. If available, perform a wavelength precision check on the gas to calibrate. The procedure for doing so is found in section 3.5. Reconnect the light from the calibration path after having completed the check. If the analyser does not pass this check, do not proceed with the calibration.
- 8a. Enter the **Measurements** mode. Let the analyser run for about 10 minutes to stabilize on the zero point. Meanwhile, connect the CC 001 cells to the calibration gas delivery system and let standard gas flow through the cells with a flow rate of 0.2 to 0.5 l/min. Make sure that the gas is vented to the outside and that there are no leaks in the system.

- 8b. If the measured zero air concentration is higher than three times the detection limit, repeat the Reference check procedure as described in section 4.1. Record five consecutive readings of the final zero air response and calculate the mean value. The detection limit is specified in the application sheets for a given path length and measurement time. The actual detection limit varies somewhat with the length and the time, but can in most cases be considered to be the same as specified in the application sheets. See sections 2.3 and 2.4.
- 8c. Insert the longest CC 001 cell in the CB 100 setup. Allow 10 minutes to ensure a stable reading.
- 8d. Perform the multipoint span check by inserting the cells in the CB 100 setup in the following sequence

$$\begin{array}{l}
 L_{c1} \\
 L_{c2} \\
 L_{c1} + L_{c2} \\
 L_{c3} \\
 L_{c1} + L_{c3} \\
 L_{c2} + L_{c3} \\
 L_{c1} + L_{c2} + L_{c3}
 \end{array}$$

Record five consecutive readings for each measurement point and calculate the mean values. The form in Figure 1.5 can be used for recording the data.

In case the test gas concentrations are generated by means of dilution, set the calibration system to deliver five upscale test gas concentrations at approximately 10, 20, 40, 60 and 80% of the measurement range. Allow at least 20 minutes for stabilization at each of the concentration levels.

- 8e. Calculate the linear relationship values of the slope (k) of the line and the zero intercept (b) on the y-axis for measured response (Y) as a function of true test gas concentration (X); $Y = k \times X + b$.
 - The intercept value (b) should be within two times the mean of the recorded standard deviation at approximately 10% of the measurement range level.
 - The variations in measurement values should be less than three times the mean of the standard deviation at each level.
 - The correlation coefficient (r) for the defined calibration relationship should be better than 0.99.

If the results are outside the above limits, first check the calibration system for possible calculation errors in true concentration values, flow measurement errors, or improper venting of the delivery system. Check analyser settings for path length, temperature and pressure values. Check the lamp type and the light level.

- 8f. The new span and offset factors should be entered as follows:

$$\text{span factor} = \frac{1}{k}$$

$$\text{offset factor} = -b$$

The new span value should not deviate more than +/- 10 % compared with previous calibrations. If it does, check the equipment, procedures as well as the calibration gas for errors.

9. Abort the measurements. Repeat the steps above with the next gas to be calibrated. Then
- Reconnect the measurement path to the system.
 - Restore the multiplexer and measurement times to the original settings.
 - Change back the system name to the initial name.
 - Reconnect the communication lines.
 - Restore the **NTP correction** and temperature and pressure correction for path one to the original settings.

Once the parameters are reset the analyser can be turned back to its normal mode of operation.

4.2.3 Calculation example

In this calculation example a span and offset calibration of SO₂ is performed. The calibration is made in accordance with the steps above.

- The monitoring path length $L = 400$ metres and the measurement range is 0 to 500 ppb.
- Three calibration cells are used, which have the lengths $L_{c1} = 0.010$ m, $L_{c2} = 0.020$ m, and $L_{c3} = 0.040$ m.
- The cylinder gas concentration $C_c = 2500$ ppm.

The following table is obtained:

Table 4.1: Example of span calibration data. All values in the two last columns are calculated as the averages from five consecutive instrument readings. The form in Figure 1.5 can be used for recording the data.

Cal.cell(s)	Cal. length	Calc. conc	Analyser response	Analyser Stand. dev.
	L_c / m	$C'_c = C_c \frac{L_c}{L}$ (X) / ppb	(Y) / ppb	ppb
-	0	0	0.8	0.5
L_{c1}	0.01	62.5	64.6	0.7
L_{c2}	0.02	125.0	129.0	0.8
$L_{c1} + L_{c2}$	0.03	187.5	194.7	0.9
L_{c3}	0.04	250.0	261.5	0.9
$L_{c1} + L_{c3}$	0.05	312.5	316.9	1.0
$L_{c2} + L_{c3}$	0.06	375.0	384.8	1.2
$L_{c1} + L_{c2} + L_{c3}$	0.07	437.5	454.2	1.3

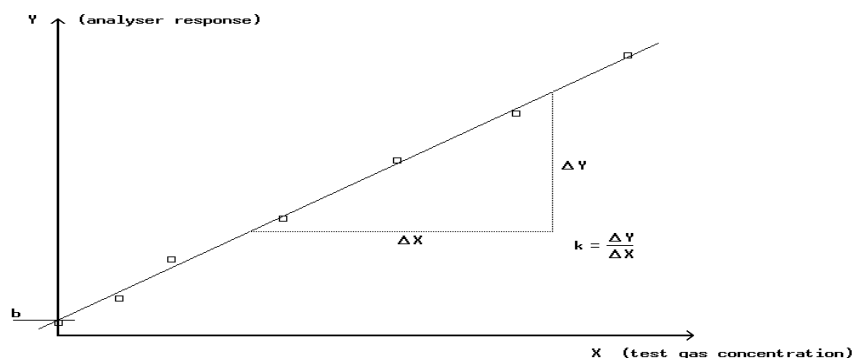


Figure 4.4. When the data pairs are plotted in a diagram, the linear response, i.e. the slope (k) and the point of intercept of the y-axis (b), is illustrated. The correlation factor (r) indicates how well the data points are fitted to a straight line. The function Non-linear correction in the analyser software can, as an alternative, be used instead of this manual procedure.

Many mini calculators have built-in functions for calculating the values of the slope (k), the intercept (b) and the correlation factor (r). If not, the factors can be calculated in the following way.

In the first step, the mean values \bar{x} and \bar{y} are calculated.

$$\bar{x} = \frac{1}{n} \sum_{i=1}^n x_i = \frac{1}{n}(x_1 + x_2 + x_3 + \dots + x_n) \quad (4.4)$$

$$\bar{y} = \frac{1}{n} \sum_{i=1}^n y_i = \frac{1}{n}(y_1 + y_2 + y_3 + \dots + y_n) \quad (4.5)$$

The slope is then calculated using the following formula:

$$k = \frac{\sum_{i=1}^n x_i(y_i - \bar{y})}{\sum_{i=1}^n x_i(x_i - \bar{x})} = \frac{x_1(y_1 - \bar{y}) + x_2(y_2 - \bar{y}) + \dots + x_n(y_n - \bar{y})}{x_1(x_1 - \bar{x}) + x_2(x_2 - \bar{x}) + \dots + x_n(x_n - \bar{x})} \quad (4.6)$$

where n is the number of data pairs (here $n = 8$).

The intercept value b is determined from the following relation:

$$b = \bar{y} - k\bar{x} \quad (4.7)$$

In order to verify the linear relation, the correlation factor r should be calculated;

$-1 \leq r \leq 1$. When $r = 0$ the parameters are independent. Here, r is expected to have a value very close to 1. r is calculated through

$$r = \frac{\sum_{i=1}^n (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^n (x_i - \bar{x})^2 \sum_{i=1}^n (y_i - \bar{y})^2}} = \frac{(x_1 - \bar{x})(y_1 - \bar{y}) + (x_2 - \bar{x})(y_2 - \bar{y}) + \dots}{\sqrt{[(x_1 - \bar{x})^2 + (x_2 - \bar{x})^2 + \dots][(y_1 - \bar{y})^2 + (y_2 - \bar{y})^2 + \dots]}} \quad (4.8)$$

Using the formulas above, and the readings in table 4.1, the following values can be calculated

$$\bar{x} = 218.8 \text{ (ppb)}$$

$$\bar{y} = 225.8 \text{ (ppb)}$$

$$k = 1.0296$$

$$b = 0.59 \text{ (ppb)}$$

$$r = 0.99984$$

As all four conditions in step 8e above are met (assuming also the third one) the calculated values for k and b can be used to adjust the span and offset factors in the instrument.

$$\text{new span} = \frac{1}{k} = 0.971 \quad (4.9)$$

$$\text{new offset} = -b = -0.6 \text{ (ppb)} \quad (4.10)$$

4.3 Function check

In a function check, a cell placed directly in front of the receiver is filled with a known concentration of a gas, and the response of the analyser is monitored. During the function check, the known concentration is added to the actual concentration along the path. Some estimations and calculations are therefore required to assess the result.

The *Function check* serves two purposes. First, it makes sure that the analyser is measuring the gas in the cell correctly. This is done by studying the step response when adding the gas in the cell. Secondly, it also makes sure that no cross-sensivities occur between the test gas in the cell and other gases. This is checked by looking at the concentrations reported for the other gases, verifying the *lack* of a stepwise change for these gases when adding the test gas. If there are cross-sensivities, they should show up as increasing deviations, and possibly changes of the concentrations within the deviation limits.

If a cross-sensitivity is discovered, please contact the Opsis representative, or Opsis AB directly. Cross-sensivities may arise when using the analyser beyond the specifications given in the product sheets or in Chapter 2, Installation criteria, in this manual. However, in certain cases, it is still possible to compensate for the cross-sensitivity in the analyser software.

The function check must be carried out under fairly stable air pollution conditions. Otherwise, the results will be hard to interpret, and could give rise to test failure.

Also see sections 4.6 and 4.7.

4.3.1 Hardware requirements

The following equipment is required to perform the function check:

- Gas cylinders with test gases of known concentrations, and with “zero air” like pure nitrogen. A “fishtank” pump providing room air can many times replace the zero air gas cylinder.
- Calibration cell CC 110 / CC 150 replacing the window in front of a receiver. There should be one cell for each measurement path.
- Gas lines from the location of the gas cylinders to the calibration cell, and from the calibration cell and out of the measurement path. The lines should be ptfe or stainless steel.
- Light meter LM 010. If possible, use the same light meter for all procedures where the light intensity is to be established.

Please see section 1.4, Safety precautions before handling any gases.

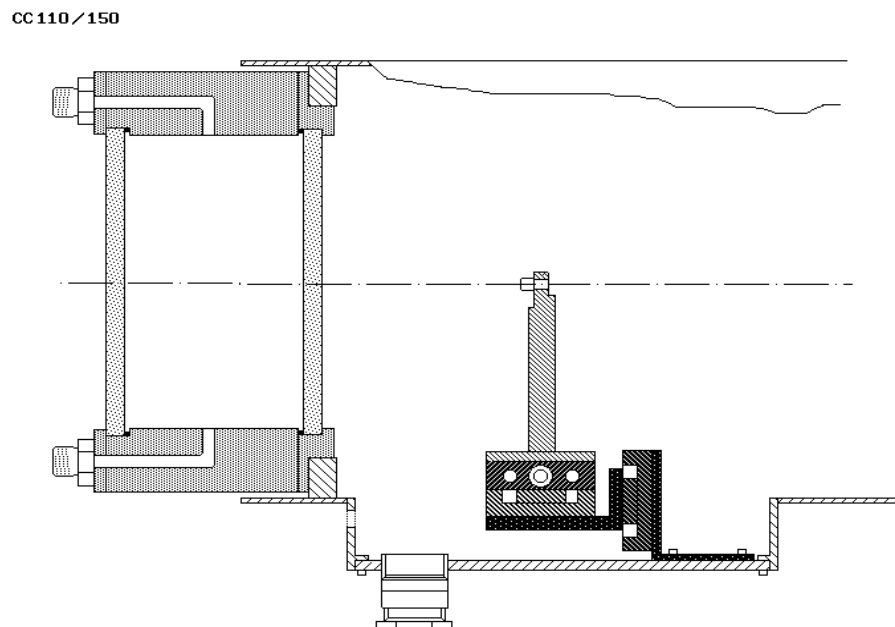


Figure 4.5. The test cell CC 110 / CC 150 should be mounted in the front of a receiver.

4.3.2 Selecting gas concentrations

The gas concentration to use depends on the expected concentrations in the ambient air. Studying measurement data, it should be possible to determine a maximum gas concentration C_m , typically an hourly or a daily maximum value. Alternatively, C_m could be a measurement range required by legislation or authorities. In any case, C_m should be selected to be in the upper part of the expected measurement range.

The test gas concentration in the gas bottle, C_t , should be selected to give a desired measurement response. Since the cells are much shorter than the measurement paths, the concentrations must be a factor of the length ratios higher. Since the test gas concentrations are added to the actual concentrations, the former should however not be related to the maximum concentrations directly, but be e.g. 50 % of the maximum value.

Thus, C_t can be calculated as

$$C_t = \frac{1}{2} \times C_m \frac{L}{L_c} \quad (4.11)$$

where L is the open-air monitoring path length and L_c is the calibration cell length. If the emitter/receiver ER 130 is used, remember to double the cell length.

This is not an exact expression, but only indicates the approximate test gas concentration. To minimize the number of test gas bottles in use, and perhaps to adapt to existing stock gas concentrations, compromises have to be made.

Each gas bottle must contain only one gas. Mixtures of gases cannot be used.

4.3.3 Performance

1. The entire function test is carried out with the analyser in normal measurement mode. The report sheet found in Figure 1.6 can be used to record the results. One sheet should be used for each path and test gas. The steps below correspond to the sections in this report sheet.

One or more cross-sensitivity can be checked as the function test is running. Any gas can be checked for cross-sensitivity, but the most interesting ones are those being measured in the same wavelength range as the test gas. To find out which gases these are, go to the **Measurement time** menu in **Measurement set-up**, and look at the **Pos.** numbers. The gases are those having the same position number as the test gas. Note that some gases do not have any potential interference gas.

2. Abort the measurements. Make a note of the path length, the temperature, the light intensity and the current system name.
3. Note the calibration cell length. It is written on the cell. For ER 130, the cell length has to be doubled. If possible, also measure the temperature in the cell. If not available, assume it is the same as in the ambient air. If a temperature correction is enabled, change it to read the temperature in the calibration cell. This may introduce a change in the reported background concentrations, but the step response when filling the cell with a calibration gas will be reported correctly.

Make a note of the test gas concentration C_t , and calculate the effective concentration C_e as

$$C_e = C_t \frac{L_c}{L} \quad (4.12)$$

C_e is the expected rise in gas concentration for the test gas.

4. Disconnect communication lines like a telephone connection. Change the system name to something else. The new system name could e.g. have the extension .TST. Go to the **Measurement time** menu, and make a note of the measurement times for each gas on each path. If more than one path is used, set all measurement times on all paths except the one being tested to zero. In addition, set all measurement times for gases not being the test or “cross-sensitivity check” gases to zero.
- 5a. Set the gas system to deliver a zero air flow of about 1 litre per minute. The flow must be selected so that no overpressure is built up inside the cell. Allow 5 minutes for stabilization. Meanwhile, start measurements of the remaining gases, using the normal measurement times, and record the light level.

When the 5 minutes have passed, make a note of the concentrations and deviations for all gases under three consecutive measurements. These are the pre-test measurements. Calculate the averages of these. The average concentration is called C_{pre} .

- 5b. Set the gas system to deliver the test gas concentration C_t . Allow 10 minutes to stabilise. Study the test gas concentration reported by the instrument. Record the concentrations and deviations for three consecutive measurements for all gases. These are the test measurements. Calculate the averages of these. The average concentration is called C_{test} .
- 5c. Set the gas system to deliver zero air measurement. After five minutes, note three consecutive measurement results. These are the post-test measurements. Calculate the averages of these. The average concentration is called C_{post} .
- 5d. The open path concentration must not have drifted too much between the pre and the post measurements. Calculate a baseline difference Δ as

$$\Delta = \left| \frac{C_{pre} - C_{post}}{C_e} \right| \quad (4.13)$$

Δ should be as low as possible. In U.S. EPA regulations it should not exceed 20%. In addition, the standard deviation in the three individual pre-, test-, and post concentrations should be less than 20% of the effective concentration C_{e0} , see below. The standard deviation for three measured concentrations is

$$s_x = \sqrt{\frac{1}{2}[(C_1 - \bar{C})^2 + (C_2 - \bar{C})^2 + (C_3 - \bar{C})^2]} \quad (4.14)$$

where \bar{C} is the average concentration of the three measurements.

The corrected concentration C_c is then given as

$$C_c = C_{test} - \frac{C_{pre} + C_{post}}{2} \quad (4.15)$$

and the error ε is calculated as

$$\varepsilon = \frac{C_c - C_e}{C_{e0}} \quad (4.16)$$

The denominator C_{e0} is equal to the effective concentration C_e for the test gas. For interference gases, instead use effective concentrations C_{e0} calculated as if these gases were the test gases.

- 5e. If Δ and the three relative standard deviations are all below 20%, the calculated error can be reported as the test result. Otherwise, the test must be repeated at a time when the background concentrations are more stable.
6. Restore the temperature correction if changed, the measurement times and the original system name, and reconnect the communication lines.

4.3.4 Calculation example

In this calculation example, a function check of toluene is described. The highest expected concentration C_m is $200 \mu\text{g}/\text{m}^3$. The measurement path length L is 480 m. With a cell length L_c of 50 mm, the test gas concentration C_t should therefore be in the range of (eqn. (4.1))

$$C_t = \frac{1}{2} \times 200 \times \frac{480}{0,050} \mu\text{g}/\text{m}^3 = 960 \text{ mg}/\text{m}^3 = 233 \text{ ppm}$$

(The conversion factor from mg/m^3 to ppm at NTP is 0.2431 for toluene.) A gas bottle with nominal 200 ppm toluene in N_2 is therefore chosen for this test. The gas certificate shows an actual concentration of 198 ± 5 ppm toluene. A reverse calculation then gives an effective concentration C_e (eqn. (4.12)) of 85 (84.8) $\mu\text{g}/\text{m}^3$.

The measurements can now be performed. The Temperature correction to NTP conditions is activated. The measurement results are shown in table 4.2.

Table 4.2: Example of function check measurement data.

($\mu\text{g}/\text{m}^3$)	pre-test	test	post test
conc., dev. #1	11.2 , 3.6	97.7 , 4.1	18.8 , 2.8
conc., dev. #2	15.4 , 2.9	99.8 , 3.9	18.0 , 3.1
conc., dev. #3	12.9 , 3.4	99.4 , 4.2	20.7 , 4.0
Averages	$C_{pre} = 13.2$	$C_{test} = 99.0$	$C_{post} = 19.2$

The temperature and pressure conditions in the cell are assumed to be the same as in the ambient air. The measurement data can therefore be used without any further temperature or pressure corrections.

Studying the data, it appears as if the background concentration has increased during the measurements. The baseline difference Δ is (eqn. (4.13))

$$\Delta = \left| \frac{13,2 - (19,2)}{85} \right| = 7,1 \%$$

and the standard deviation in the measured concentrations are 2.1, 1.1, and 1.4 $\mu\text{g}/\text{m}^3$ respectively (eqn. (4.14)). All variations are below the recommended limit of 20 %, and the measurement data can thus be used. The corrected concentration C_c is

$$C_c = 99,0 - \frac{13,2 + 19,2}{2} \mu\text{g}/\text{m}^3 = 82,8 \mu\text{g}/\text{m}^3$$

(eqn. (4.15)) giving an error ε of (eqn. [4.16])

$$\varepsilon = \frac{82,8 - 85}{85} \% = -2,6 \%$$

This error is within the specification of the test gas concentration.

4.4 Light attenuation test

By deliberately attenuating the light that is captured by the receiver, it is possible to estimate the analyser's sensitivity to changes in light intensities. A light attenuation test should be carried out for each path and each gas, since the result may be depending on both the path length and the wavelength region.

The attenuation must be performed with some care. It is not possible to simply screen off the receiver by a solid obstacle placed e.g. halfway up in front of the receiver window. This will lead to an asymmetric filling of the fibre end, giving rise to the undesired dark spots and circles visible when directing the fibre end towards a white piece of paper. Instead, a grid built up by a large number of equally distributed small holes should be used.

4.4.1 Hardware requirements

The only equipment needed for this test is a set of grids, typically three of them with a transmission of 1/2, 1/4 and 1/8, and a light meter LM 010. The grids are available from Opsis AB, or they can be manufactured from a 0.5 mm aluminum plate. The ratio between the hole diameter d and the partition a (see Figure 4.6) should be

Transmission	d/a
1/2	0.80
1/4	0.56
1/8	0.40

a should be fairly small, 5-10 mm. The aluminum plate must be big enough to cover the entire receiver entrance.

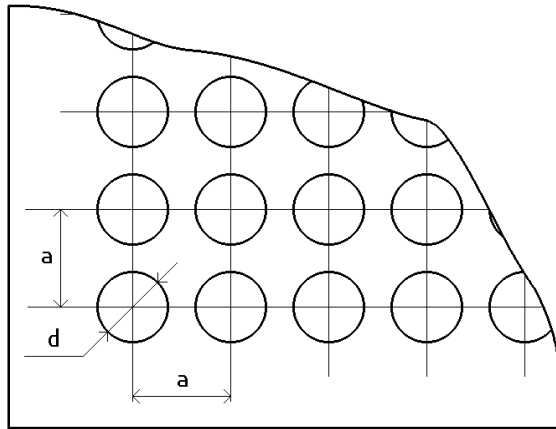


Figure 4.6. Part of a light attenuation grid.

Note: the transmission values will be squared using an ER 120/130 unit.

4.4.2 Performance

1. The procedure for performing a light attenuation test is described below. A suitable report sheet can be found in Figure 1.7. The step numbers below correspond to the different parts of this report sheet. Before starting the test, stop the measurements and make sure that all measurement paths are well aligned, see section 3.1.
2. The light attenuation test is performed with the analyser in normal measurement mode. Since the test may result in bad measurement data, it is important to separate test data from the normal readings. Therefore, disconnect the communication line, make a note of the original system name, and change it to something else, e.g. with the extension .LGT. Go to the **Measurement time** menu under the **Measurement setup**, and make a note of all measurement times. If a multiplexer is used, set all measurement times to zero, except for the first path.
3. Without using any attenuator, measure the light intensity from the current path.
- 4a. Start the measurements again, and make a note of the concentrations, deviations and light levels for the gases being measured, still not using any attenuator.
- 4b. Put the 1/2-grid in front of the receiver, make a note of the achieved light intensity in lux, and continue to record a set of concentrations deviations and light levels.
- 4c. Same as 4b, but with the 1/4-grid.
- 4d. Same as 4b, but with the 1/8-grid.
- 4e. If more than one measurement path is used, set the measurement times for the current path to zero, and restore the times for the next path. Repeat from step 3 until all paths have been tested.
5. Restore all measurement times and the system name. Reconnect the communication line.

The test result is first of all a relation between the light intensity and the light level for different paths and gases. Secondly, if any deviation increased as the light was attenuated, the test gives a good idea of what light levels are required for having the instrument to operate at its peak performance. Test data are useful when estimating what variations in light levels are acceptable, see section 3.1.

4.5 Oxygen backgrounds

Oxygen is a major absorber in the wavelength window where some aromatic hydrocarbons like toluene are measured. However, the high oxygen concentrations make the oxygen absorption non-linear with the measurement path length. The cross-section of oxygen must therefore be recorded individually for each measurement path. This is done by utilizing the function **Make new cross-section** tile in the advanced calibration menu. See also section 5.4.

4.5.1 Hardware requirements

The hardware required to record an oxygen background is exactly the same as is being used for a reference check, see section 4.1.

4.5.2 Selecting a proper recording occasion

As stated above, the light from the actual measurement path is used to record the oxygen interference spectrum. This, however, gives rise to a problem, since there is always some hydrocarbon content along the path. As the O₂ background is subtracted from the measurement spectrum, there will thus also be a subtraction of hydrocarbon levels, giving an offset error to the hydrocarbon readings.

The offset error in raw data cannot be avoided, but it can be minimised and accounted for in some different ways:

- Record the oxygen background when the aromatic hydrocarbon (HC) concentrations are known to be negligible, e.g. when it is windy and the traffic intensity is low. An offset error should then not occur. A negligible concentration is a concentration with the size of the analyser detection limit, or lower.
- If negligible HC concentrations cannot be guaranteed, then the spectrum can still be recorded. The offset error will then be noticeable, but it can then be accounted for by post-measurement data processing, see section 5.3, providing that the concentrations at some occasion do go down to negligible levels. This is the *statistical* approach.
- If none of the above methods are applicable, another solution is to record the oxygen spectrum while simultaneously monitoring the HC levels by another instrument. The correct offset value can then directly be set, assuming that the hydrocarbons are equally distributed along the path. The recording must therefore be made under well-ventilated (well-mixed) conditions, giving rise to an equal distribution. This is the *measurement* approach.
- Proper offset values can also be determined by letting the instrument measure in parallel with another monitor for a longer period of time, typically two or more weeks. See section 4.5.3, paragraph 5g.

4.5.3 Performance

1. An oxygen background recording is made for one path at a time. A report sheet suitable for record-keeping can be found in Figure 1.8. The steps below correspond to the different parts of this report sheet.
2. Perform a complete system check according to section 3.2. If the analyser does not pass this check, do not proceed with the recording.
3. Make a wavelength precision check for the gases for which new oxygen backgrounds are to be recorded. The procedure for doing this is described in section 3.5. Do not proceed with the recordings unless the analyser passes this test. Go to the **Calibration** menu, then **Advance calibration menu**, and select the **Make a new crosssection tile** function. The gases to check are indicated as **Valid**.
4. Make sure that the lamp in the calibration light source is of the type B, and switch on the lamp. Let the lamp stabilize for 30 minutes. Stop the measurements and measure the light intensity on the measurement path using the LM 010 light meter. Optimise the light from the path. Direct the fibre optic cable from the measurement path towards a white piece of paper, and make sure that the light spot is smooth without any dark spots or rings.

Adjust the calibration bench setup so the light intensity is maximized, and so no dark areas appear in the light spot. Connect the fibre to the analyser, and run a second system check. If P3 fails, reduce the light intensity by defocusing the emitter mirror, and repeat this step.

A part of the recording procedure is a test measurement. In order not to mix test data with actual measurement data, the communication line should be disconnected, and the system name changed to something else, e.g. with the extension .OXB. Also note the original measurement times for all paths and gases.

- 5a. Record a new reference spectrum for each group of gases by selecting **Reference calibration** in the **Calibration** menu. Set **Skip reference check** to **Yes**, tick the gases to record, and choose **Start calibration**. Follow the instructions on the screen. The reference recording function must have been set up before starting this procedure, see section 4.1.2.
- 5b. Go to the **Make a new crosssection file** function, and tick the gases to record the background for. Set the recording time to 300 seconds, and let the analyser record the background spectrum.
- 5c. When prompted, disconnect the light from the measurement path, and connect the light from the calibration bench. It is generally an advantage if the fibre from the measurement path can be used on the calibration path, but this may not be possible for practical reasons. Record the reference spectrum for 300 seconds.
- 5d. Finish by recording the spectrum from the CA 004 lamp. 10 seconds is a sufficient recording time. Answer yes, if a question “Do you want to use this for AIR” appears. Then other hydrocarbons measured within the same spectral range will be recorded as well.

-
- 5e. The result of the recordings can now be checked. Go to the span/offset menu, and make a note of the existing offset value for each gas that has been activated. Then set the offset to zero. Go to the **Measurement time** menu, and set the measurement times for all other paths and gases to zero.
- 5f. Let the analyser start measuring, and observe at least three consecutive readings of concentration, deviation and light level for each gas. Compared to the readings before starting this procedure, the deviations should be about the same or lower. The concentrations should all be of the same size as the deviations.
- 5g. The final offset for each gas can now be set. The value could be based on either of the following considerations:
- It should be set to 0.0 if the HC concentrations are known to be negligible.
 - It should also be set to 0.0 if the post-measurement data processing according to section 5.3 is fully implemented.
 - It should be set to the readings of a reference instrument, if the oxygen recording was performed while monitoring the gas concentrations with an independent measurement system under well-mixed conditions.
 - The offset value might possibly also be set to some value based on experience. The only purpose of doing so is to have the instrument reporting roughly correct values. Post-measurement data processing is still necessary to find the final zero level of the instrument.
 - The last option is to make parallel measurements during a longer period of time, typically some weeks, having a zero offset in the instrument. During this period, there should be at least a few occasions when well-mixed conditions prevail, giving stable readings from both instruments. Comparing the two sets of data at the end of the parallel measurement period, a new offset value can be determined and entered in the analyser. This is the *only* situation where the offset value should be changed without recording a new oxygen reference at the same time. This approach increases the number of periods for which different offset values have to be applied in post-processing of data, see section 5.4.
6. Restore the system name, and reconnect the communication lines. Also restore the original measurement times, if changed throughout the course of this procedure.

If possible, avoid fine-tuning the offset values after having recorded the oxygen background and finally started the measurements. It only leads to more complicated and extended data validation procedures.

4.6 Precision test

A Precision test is defined in the U.S. EPA 40 CFR Part 58 regulations. It is carried out exactly as a Function check, see section 4.3, but with the following exceptions:

- The test gas concentration is fixed so that the effective concentration is 8-10 % of the pre-defined measurement range. In most cases the range is 0-1.0 ppm, giving effective concentrations of 80-100 ppb. If the range is higher, the effective concentration is increased correspondingly.
- A precision test does not include any tests of cross-sensitivities.
- The baseline difference must not be above 20 %, as recommended in the *Function check*. The USEPA regulations do not give any value limiting the standard deviation in the pre- test-, or post measurement concentrations.

Utilizing a CU 004/007 valve box, it is possible to have carry out precision test fully or semi-automatically.

Please refer to the above mentioned regulations for more information.

4.7 Accuracy audit test

An Accuracy audit test is defined in the U.S. EPA 40 CFR Part 58 regulations. The test is carried out as a Multipoint span/offset calibration, see section 4.2, with the following modifications:

- Accuracy audit is a multipoint test, where the effective gas concentrations should correspond to 3-8 %, 15-20 %, 35-45 % and 80-90 % of the upper range limit. The upper range limit is typically 1.0 ppm.
- The procedure is a *test* to verify the instrument function. Any modification of the span or offset values is not included in the test.
- The test result is reported in the same way as the Precision test / Function check.

In principle, it is also possible to perform an Accuracy audit test as a Function check, but for practical reasons the span/offset calibration approach is recommended. Please refer to the above mentioned regulations for more information.

Data validation is the final step towards quality assured measurement results. The validation can be divided into the following groups:

- Analyser function and performance. The procedures described in Chapter 3, Hardware function and Chapter 4, Measurement performance should ultimately confirm that the measuring system is operating as intended. If not, the consequences of the error must be considered.
- Light levels and deviations. Each measured concentration is accompanied by a concentration deviation and a light level. These two parameters should always be used to verify the quality of the concentration measurement.
- Hydrocarbon zero levels. Depending on how hydrocarbon gas concentrations were measured, a post-measurement correction may have to be done. Doing so is actually not a validation itself, but a procedure that must be carried out prior to or together with the actual validation.

Many of the data validation procedures only need to be performed once, even if the data is used several times. To minimize work, a proper record should be kept of the status of the measurement data for different time periods. A report sheet for doing so can be found in Figure 1.9 in this manual.

The Opolis Enviman software for data acquisition and presentation allows full implementation of filtering rules for data validation on a real-time basis.

5.1 Collecting measurement data

Every single set of measurement data is stored in the analyser. From there it can be transferred either on floppy disks or (more usual) through modem communication.

Data can be extracted from the analyser in two considerably different ways: either by transferring *all* measurement information, or by time averaging the data in the analyser and then transfer the *averaged* data values.

In the latter case, the averaging rules are built into the analyser software. The rules include rejection of data with “no light”, with “negative deviations” providing that the concentration is above two times the deviation, and with “negative light levels”. See the analyser

software manual for an explanation of these conceptions. The analyser does not provide any observation limits for calculating an average.

The rules above may not provide the best concept for data validation. In addition, measurement problems may be hidden by this averaging strategy. It is therefore recommended *always to extract all measurement data from the analyser*, and base the validation process on this complete set of data. This is accomplished by using “zero” integration time when extracting the data, see the software manuals.

The only reason for using averaging is that, if the transfer speed is very low, if the storage capacity at the workstation is limited, or, possibly, if the data is only used for routine system surveillance.

5.2 Analyser function and performance

The procedures described in Chapter 3, Hardware function and Chapter 4, Measurement performance, should preferably lead to a confirmation that the measuring system is working in the desired way.

If this is not the case, the consequences of the discovered problem must be considered before using the measurement data. Possible problems could lead to either of three actions:

1. It may turn out that the problem actually did not affect the measurement data. This could e.g. be the case if the light levels have dropped, leading to a realignment of an emitter or a receiver, but the Light attenuation test (section 4.4) makes it plausible that this does not affect the measurement performance.
2. In some cases, the problem may influence the measurement data, but the error can be corrected in post-measurement adjustments. An example of this is if a span/offset calibration (section 4.2) leads to new values for the span or the offset. Old measurement data should then be corrected to compensate for the bad original span and offset values.
3. If a problem is found to give bad measurement data which cannot be corrected, one has to look at the quality assurance records to find the last occasion when the problem was not reported. The measurement data between these two occasions should then be examined carefully.
 - In many cases, it may be possible to identify a certain date and time when the error occurred. Then, only data after this event has to be disqualified. An example of this might be if the analyser at some occasion is exposed to a mechanical transient leading to an error in grating positioning. The occasion is then identified by consequently negative deviations in measurement data, starting at a certain date and time.

- In worst case, the error cannot be identified to have arisen at a certain time. Then, measurement data for the entire period may have to be discarded.

It is not possible to exactly describe every single imaginable error and its implications on measurement performance. Instead, common sense and experience should guide the data management. Every Opsis representative have a vast experience in data handling, and should therefore be able to give advice in almost any situation.

5.3 Light levels and deviations

The evaluation of a dataset should normally include an analysis of the data quality. Since each data point includes information on concentration and light levels as well as a standard deviation of the result, it is possible to perform a comprehensive study.

The light level is varying with the meteorological and atmospherical conditions as well as with the stability of the emitter/receiver platforms. When the light is decreasing the standard deviation is increasing, since the signal-to-noise ratio, i.e. concentration divided by deviation (C/D), is decreasing. A scatter plot of light level versus standard deviation will therefore typically show a decay down to a point where the noise becomes the prevailing factor.

However, the standard deviation tends to increase also when high pollution levels are measured. This is normal since the signal-to-noise ratio, S/N , then is a constant. Those values are characterized by a constant light level and are found along a horizontal line in such a scatter plot (see below).

A proper statistical treatment of a dataset should therefore normally not be based on a fixed upper standard deviation limit, since such a limit will reject peaks of high pollution levels. In order to avoid this the analysis should include conditions on the signal-to-noise ratio as well. How to proceed is described in the steps given in sections 5.3.1 and 5.3.2 below. In order to illustrate the procedure an example is also given.

Please note that the analysis must be applied for each individual gas in each application, since the light levels, the standard deviations and the detection limits vary with each applications, due to differences in path lengths, monitoring times, detection limits, etc.

5.3.1 Lowest acceptable light level

The diagram below shows a typical light level versus deviation scatter plot. No integration time is used, i.e. all data points are included. Two groups of data can be defined. The first one is found along a straight line and is characterized by a constant light level. This group includes the periods with high pollution levels. The second group of data is curve shaped, where the deviation increases with decreasing light level.

The curve can be used to find values on the lowest acceptable light level L and a corresponding value on the standard deviation D_i . Both factors are important for the analysis.

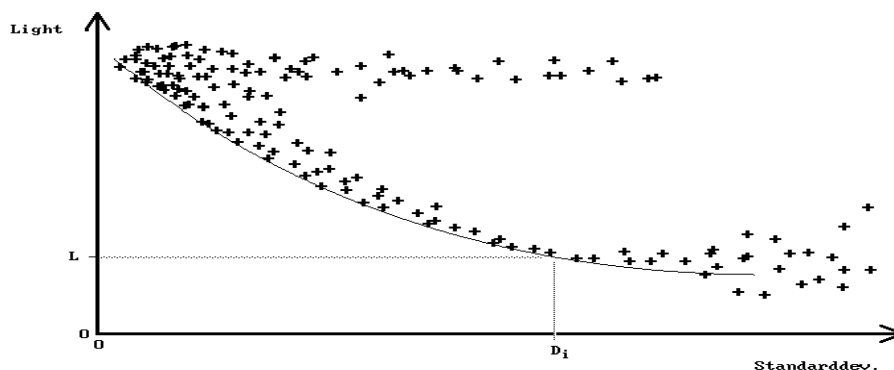


Figure 5.1. Light level versus standard deviation for an arbitrary gas.

The following rules of thumb can be applied:

1. Draw a curve directly underneath the scattered points in the diagram.
2. Find the point on the curve where the noise becomes dominant.
3. Follow the line uphill to approximately 1/4 or 1/3 of its length. This point defines the light level L and the deviation value D_i .

The values of L and D_i can be recorded on the report sheet found in Figure 1.9.

5.3.2 Signal to noise ratio

Once the lowest acceptable light level is defined the influence from possible interferences should be considered. An interfering substance will make the standard deviation for the component in test increase. However, this influence must be separated from the normal behaviour where the standard deviation increases with the concentration when measuring high pollution levels.

The parameter to use is the signal-to-noise ratio S/N , i.e. the concentration divided by the deviation, C/D . From a scatter plot of concentration versus standard deviation an appropriate value of C/D can be estimated.

The bad data points are found in the lower, right hand part of the diagram. Starting at the point D_i on the x-axis a straight line should be drawn, below which the rejected data points are found. The task is to find a value for the slope of the line, i.e. a value of C/D . There are several possibilities.

- One way is to look at sequences of data points with high concentrations, which are known to be accurate. From the ratio concentration / deviation in each point the val-

ue is given directly. However, one condition is that the ratio is pretty constant for several data points in a sequence.

- Another way is to estimate a value from the scatter plot. From the slope of the line, along which most of the data points are found, a value of C/D is given. In some cases this way is the easiest, see the examples below.
- A third way is applicable when the data points are scattered without obvious trends. From the questions: –What is a reasonable upper value of the deviation when measuring 25 ppb, 50 ppb? it ought to be possible to estimate a value of C/D .

A guideline value of C/D is 10. The obtained C/D value can be recorded in on the report sheet found in Figure 1.8.

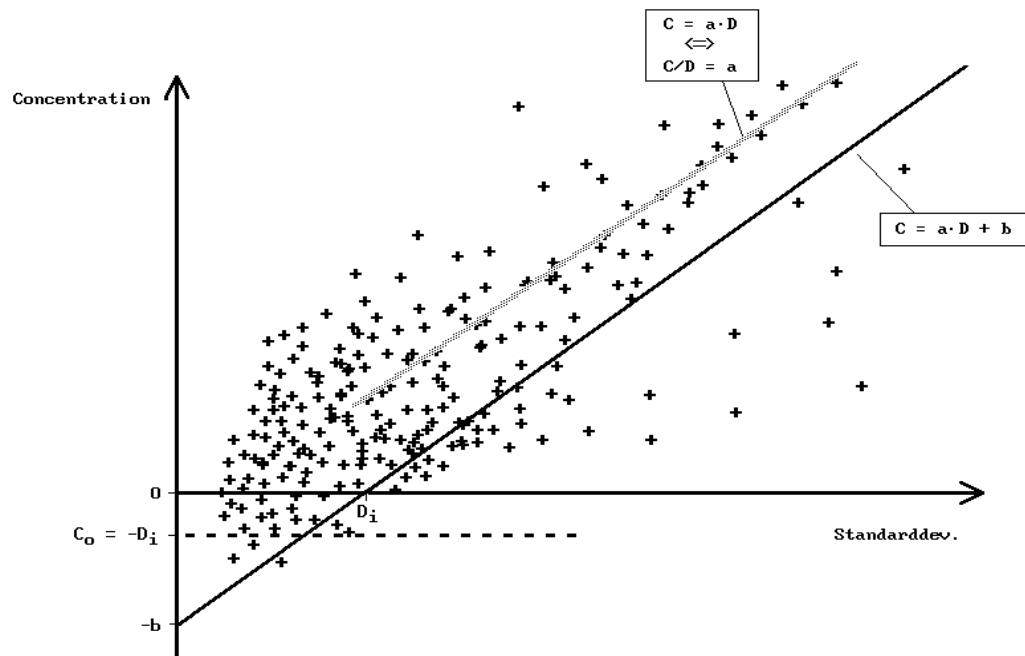


Figure 5.2. Concentration versus standard deviation for an arbitrary gas. Also see section 5.3.3.

Once a value of C/D is found (the shaded line in the diagram) the final condition can be set.

From the diagram it is obvious that the shaded line split the data set in two approximately equal halves. Using that line as the quality limit would reject many good data points as well. However, by moving the line sideways so that the point of intersection on the x-axis is D_i , as previously defined, the number of rejected data points is considerably smaller. This line is the solid one in the diagram.

The shaded line can mathematically be written as

$$C = a \cdot D \quad (5.1)$$

The solid line can consequently be written as

$$C = a \cdot D + b \quad (5.2)$$

We know the value of a ; $a = C/D$.

The constant b is found by setting $C = 0$ in the equation so that $D = D_i$. From this follows that

$$\begin{aligned} a \cdot D_i + b &= 0 \\ \Leftrightarrow \\ b &= -a \cdot D_i \end{aligned} \quad (5.3)$$

5.3.3 Lowest acceptable concentration

If the solid line in Figure 5.2 would be the only limit for accepting measurement data, there would a risk of accepting large negative concentrations for low deviations close to zero. To avoid this, a second (dashed) line given by

$$C = C_0 \quad (5.4)$$

is introduced in the diagram. Negative concentrations have to be accepted, since they are a natural part of the measurement noise. However, they can only be accepted if they are in the same range as the lowest noise level, represented by D_i in the figure. Thus,

$$C = C_0 = -D_i \quad (5.5)$$

is a reasonable lowest acceptable concentration, when measuring below the detection limit.

5.3.4 Using Enviman ComVisioner

The light level requirement together with eqns. [5.2] and [5.5] can be written directly as a *condition* for a gas parameter in ComVisioner. For example, with $L = 20$, $a = 10$ and $D_i = 2 \mu\text{g}/\text{m}^3$ (see the example in section 5.3.4), the condition becomes

$$(L > 20) \ \& \ (C + 2 > 0) \ \& \ (C > 10 \cdot \text{ABS}(D) - 20)$$

The parenthesis are not required, but added for clarity. Note that the absolute value of the deviation is used. This is necessary since the analyser uses a negative sign in front of the deviation as a warning flag for a possible bad evaluation. The sign is mathematically irrelevant, and bad measurement data will be removed by the condition anyway. In addition, $(C + 2 > 0)$ is a necessary rewrite of $(C > -2)$, required by the software.

In addition to the procedures above, hydrocarbon measurement results may require adjustment of the baseline (offset) prior to any use. See section 5.4 for more information.

Also note that a filter set in the analyser may tag the light level with a minus sign. Any data set with negative light level will be rejected by the condition above.

5.3.5 Example

The two scatter plots are shown below.

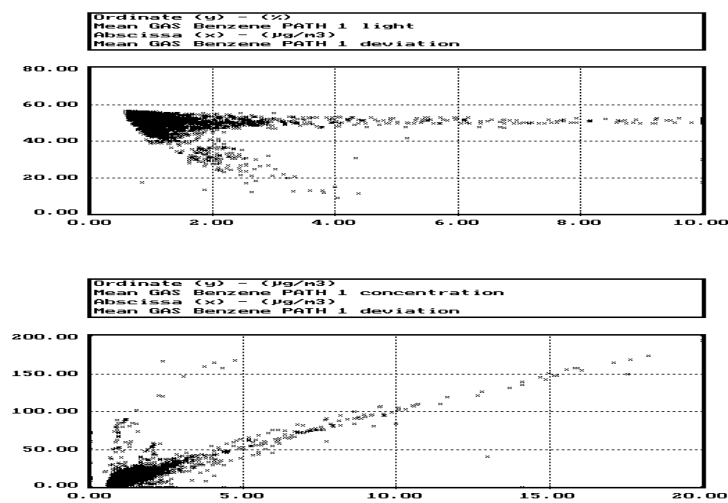


Figure 5.3. Printouts showing an example of how the filter parameters can be found.

Discussion:

- In the top graph the two previously discussed groups of data are possible to identify. One group is characterized by constant light level whilst the other one follows a distinct curve. A lower light level of 20 % is set on trial. This corresponds to a standard deviation of $D_i = 2.0 \mu\text{g}/\text{m}^3$.
- In the bottom graph a signal-to-noise ratio of $150/15 = 10$ is very distinct. The data points with constant light levels in the upper graph are found along the straight line with a constant signal-to-noise ratio.

For the analysis the following factors are defined.

$$L > 20 \%$$

$$D_i = 2 \mu\text{g}/\text{m}^3$$

$$C/D = a = 10$$

From equation [5.3] b can be calculated to $-10.2 \mu\text{g}/\text{m}^3$, i.e.

$$b = -20 \mu\text{g}/\text{m}^3.$$

As a summary, equations [5.2] and [5.5] in conditional form is written as

$$C > 10 \cdot D - 20 \text{ and } C > -2$$

5.4 Aromatic hydrocarbon zero levels and deviations

The offset arising when measuring some aromatic hydrocarbon gas concentrations has already been discussed in section 4.7. Some gases which may show offsets are benzene, toluene, xylenes, trimethyl-benzenes and ethyl-benzene. Other aromatic hydrocarbons like styrene and phenol are not affected. As stated in section 4.7, it is necessary to make post-measurement adjustment of the baseline, unless an accurate calibration was made, typically when the oxygen background was recorded.

When evaluating the data, there will be one offset value determined for each aromatic hydrocarbon gas and for each path. This offset value should be used for that time period during which a particular oxygen background was in use. When the background is rerecorded, the offset value will change.

The oxygen background is recorded at installation, and when the deviations start rising, see section 5.4.2 below.

5.4.1 Finding the zero level

The concentration baseline, i.e. the offset, can be found by studying measurement data over longer time periods, during which the hydrocarbon concentrations are likely to drop to background (or detection limit) levels. If the background level for the current time period is expected to always be above the detection limit, an intercomparison with another hydrocarbon monitor may be necessary to establish the actual level of the baseline.

The baseline level probably will be changed as soon as a new air spectrum is recorded. It is therefore necessary to keep track of during which time periods a certain background spectrum was in use at a certain path and compensate for this by using different offset factors during data studies for different time periods. The baseline will also change if the offset factor in the opto-analyser is changed for some reason. To minimize the number of time intervals during which different offset factors are to be used, the analyser offset factor should normally *not* be changed, unless an oxygen background is recorded at the same time.

Before doing any adjustments, the detection limit for each gas and path should be considered. The Opsis application sheets specify the detection limit on a 500 m path, with a 1 minute measurement time. The actual detection limit depends slightly on the actual length

and time. In practice, it is however usually close to the specified one, even if the length and time differs from the specifications.

The detection limit sets the precision with which the baseline can be determined.

To establish the offset, all measurement data for the particular time period should be filtered according to section 5.3. In this way, bad light levels or interferences will not influence the baseline value.

In the next step, all data points are plotted against time, as shown in Figure 5.4. The actual detection limit should be considered when establishing the baseline level. When measuring close to the detection limit, also negative concentrations will appear as a natural part of the measurement noise. The horizontal baseline is therefore *not* located at the *lowest* value, but it is *centered* in the low-value measurement noise. Note that there is no point in trying to establish the location of the baseline better than the order of magnitude of the actual detection limit.

The baseline value should be subtracted from the raw gas concentration whenever studying measurement data any further. Since a new baseline only need to be determined when a new oxygen background is recorded, the process of determining the offset value is basically a part of the installation procedures, however delayed in time.

The above description is only valid in measurement situations where the actual gas concentration is expected to go down to zero, at least at a few occasions throughout the time period.

If the background level is expected to be above the detection limit during the entire time interval, the baseline value should be subtracted by this background in order to yield the correct offset. In this way, the lowest corrected concentration values will correspond to the expected background. The actual background can then only be determined by parallel measurements with another instrument.

Two examples of baseline determination are given below.

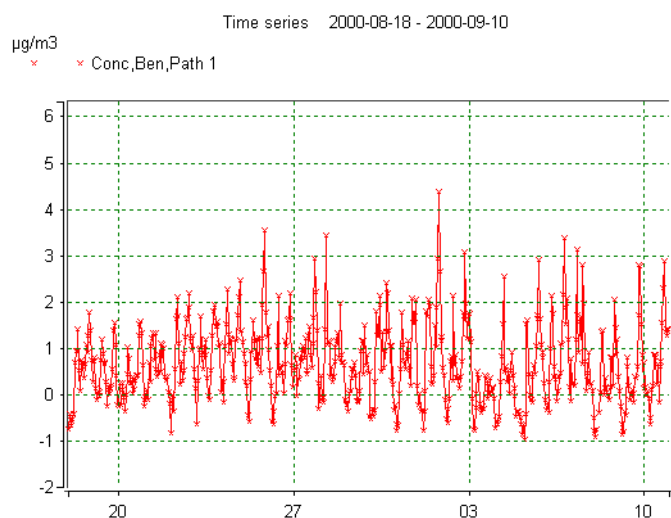


Figure 5.4. A plot of validated benzene concentrations. The base line appears to be located at approx. $-1 \mu\text{g}/\text{m}^3$, which thus is the value each concentration should be added with, in order to represent the true concentration in the air.

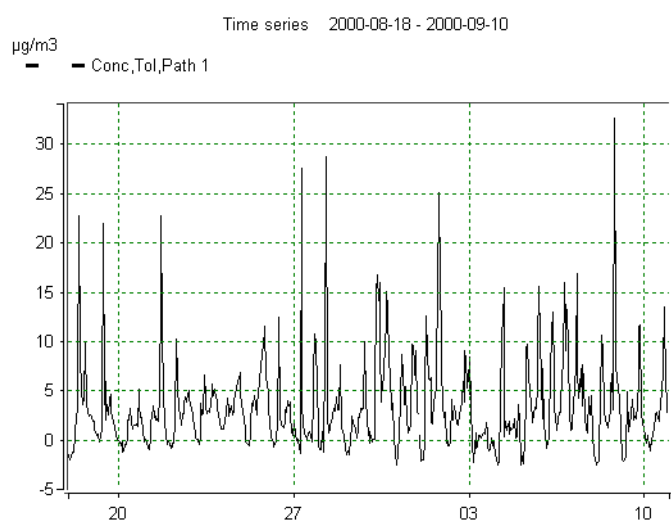


Figure 5.5. Validating toluene concentrations. The site is such that the concentrations occasionally does go down to zero. The analyser was operating with a zero offset, giving rise to a negative baseline at approx. $-2 \mu\text{g}/\text{m}^3$. (Thus, the background toluene concentration was $2 \mu\text{g}/\text{m}^3$ when the oxygen background was recorded). The value $+2 \mu\text{g}/\text{m}^3$ should therefore be added to all toluene gas concentrations recorded on this path during the displayed time interval.

With the introduction of the high resolution BTX grating in 1998, the effects from oxygen backgrounds was minimized, so that new or upgraded analysers only will need minor baseline/offset adjustments, typically in the range of the detection limits.

5.4.2 Aromatic hydrocarbon deviations

Oxygen backgrounds could be recorded at installation, as described in section 4.7. In addition, these backgrounds could also be (re-)recorded when there are noticeable increases in any of the aromatic hydrocarbon deviations.

An increase in deviation indicates a problem in the spectral fitting of the analyser. It could either be due to an interfering gas, giving rise to a measurement spectrum that cannot be fully fitted, or it could be due to changes in the mechanical or optical components of the analyser. In the latter case, the deviation increase will become permanent. When the deviation consistently increases to or above the detection limit, a new oxygen background should be recorded.

A deviation increase is easily detected by studying the deviation as a function of time, in the same way as the gas concentration was studied to establish the baseline level. In this way, an average “normal” deviation value can be found. In a good operating system, the deviation stays at this level, possibly except for episodes with very high concentrations. A new oxygen background is only required when the average deviation level increases also for low-level or background concentration measurements.

It is important not to mix a permanent deviation increase with a temporary increase due to an unknown interfering gas.

